Final DG Scenario Development Report

For:

Air Quality Impacts of Distributed Generation

California Energy Commission Contract # 500-00-033

Submitted to:

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September 24, 2003

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List of Acronyms

AGT	Advanced Gas Turbine
CARB	California Air Resources Board
CACM	Caltech Atmospheric Chemistry Mechanism
CEC	California Energy Commission
CGT	Conventional Gas Turbine
CHP	Combined Cooling, Heating and Power
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DER	Distributed Energy Resources
DG	Distributed Generation
FC	Fuel Cell(s)
GT	Gas Turbines(s)
HHV	Higher Heating Value
HT	High temperature
ICE	Internal Combustion Engine
LADWP	Los Angeles Department of Water and Power
LT	Low temperature
MCFC	Molten Carbonate Fuel Cell(s)
MTG	Microturbine Generator(s)
NH_3	Ammonia
NOx	Nitrogen Oxides
NG	Natural Gas
PEMFC	Proton Exchange Membrane Fuel Cell(s)
PM2.5	Particulate Matter (less than 2.5 microns)
PM10	Particulate Matter (less than 10 microns)
PV	Photovoltaics
SCAG	Southern California Association of Governments
SCAQMD	South Coast Air Quality Management District
SCE	Southern California Edison
SCR:	Selective Catalytic Reduction
SoCAB:	South Coast Air Basin
SOFC:	Solid Oxide Fuel Cell(s)
SOx:	Sulfur Oxides
VOC:	Volatile Organic Compounds

1 INTRODUCTION

Distributed Generation (DG) has a strong potential to play an important role in the more efficient and competitive emerging electric power industry. DG can fulfill the needs of many customers and provide benefits in many applications. Among them, DG can provide critical customer loads with emergency stand-by power; support available capacity to meet peak power demands; improve user power quality; and provide low-cost total energy in Combined Cooling, Heating and Power (CHP) applications.

California, as one of the first regions in the US facing the restructuring of the electric power industry, will likely be one of the first locations with widespread adoption of Distributed Energy Resources (DER). According to the strategic plan for DG developed by the California Energy Commission (Tomashefsky and Marks, 2002), more than 2,000 MW can be currently classified as DG in California. From January 2001 through May 2002, 192 DG projects were proposed throughout the state, representing more than 400 MW of new generation.

The implementation of a paradigm shift from central generation to distributed generation would result in significantly different emissions profiles with increased and widely dispersed stationary source emissions increases in several air basins (compared to central generation outside of the basin). One would like to determine whether increases in pollutant emissions in the air basin would lead to ambient ozone levels that exceed the proposed new 8-hour ozone standard. Also, increases in NOx emissions can trigger increases in secondary particulate formation that could impact compliance with proposed Federal $PM_{2.5}$ standard. The determination of these and other potential air quality impacts is of significant strategic importance to the advancement of DG technology. In addition, these impacts need to be assessed before public policy decisions are made to facilitate or discourage application of DG in urban air basins.

In a recent study Lents et al. (2000) determined the forms of DG that are most likely to improve environmental quality, and to reduce air pollution in California. The strategy they adopted was to comparatively analyze the level of pollutant emissions associated with a range of DG technologies and fuel types. They concluded that only the lowest emitting DG technologies (e.g., fuel cells) with significant waste heat recovery are even marginally competitive with the emissions performance of modern combined cycle power production from a criteria pollutant emissions perspective. However, in cases where waste fuel is being flared or directly emitted within the basin (e.g., in landfills), in-basin pollutant emissions can be reduced if this fuel is used to drive the DG units.

Ianucci et al. (2000) evaluated the net air emissions effects from the potential use of cost-effective distributed generation in California. First, the study used the available DG technologies and their costs to assess the economic market potential for DG for both utilities and large commercial/industrial customers in years 2002 and 2010. Second, total emissions were calculated for the selected years, given the estimated market penetration levels for each type of DG, and compared with central-generation only scenario. The study concluded that the current California central generation mix is so clean that virtually no cost-effective distributed generation source could lower net emissions, even when transmission and distribution electric line losses are included. Fuel cells resulted in a marginal market penetration, due their high cost, but showed great promise because fuel cell air emissions are much lower than central station generation.

Significantly, neither of the above studies determined the air quality impacts associated with the DG emissions. The results and conclusions of these studies were based purely on an emissions assessment (or accounting). Air quality is affected by a host of factors over and above the direct emission of criteria pollutants that the DG may emit. These factors include homogeneous and heterogeneous atmospheric chemistry, mass transport, photochemical reactions, spatial and temporal variations in emissions, geography, meteorology, etc. These air quality impacts can only be determined using a detailed and fully coupled air quality model that includes these phenomena.

The present effort, funded by the California Energy Commission (CEC) under the Public Interest Energy Research (PIER) program, is both determining realistic scenarios for DG application in the south coast air basin (SoCAB) of southern California and assessing air quality impacts with a detailed air quality model. The two primary objectives are to: (1) construct a set of distributed generation implementation scenarios for the SoCAB of California; and (2) determine the potential air quality impacts of DG in the SoCAB by application of these scenarios to a detailed air quality model for SoCAB. The model is a state-of-the-art, discretized (into 5-km X 5-km cells), comprehensive modeling system for urban air quality simulation based on many years of SoCAB simulation efforts at the California Institute of Technology (CIT). This report presents the characterization process involved to develop the DG implementation scenarios and briefly describes the DG scenarios that have been developed.

2 CHARACTERIZATION OF DG SCENARIOS

To fully characterize how distributed generation (DG) resources may be implemented in the south coast air basin of California, one must describe in detail a significant set of parameters that define the operating characteristics of the DG units, their spatial and temporal distribution throughout the basin, and other characteristics of the particular instance of DG use in the basin. A compilation of the entire suite of information and characteristics that are required to fully describe all of the DG characteristics as installed in SoCAB is called a "DG Scenario."

The Advanced Power and Energy Program (APEP) team has determined that the space required to fully define a DG Scenario can be characterized by a set of seven parameters and various factors that are subsets of these parameters. The seven parameters have been identified to fully characterize a DG scenario are presented schematically in Figure 1. The seven parameters of Figure 1 include: (1) the total fraction of SoCAB energy needs that are met by DG in the scenario, (2) the allocation of DG resources to meet that need, (3) the emissions associated with each DG unit type, (4) the spatial distribution of the DG in SoCAB, (5) the operational duty cycle of each DG, (6) the accounting for any emissions that are displaced by installation of the DG, and (7) other estimates that are required to account for the DG and relate the emissions to requirements of the air quality model (AQM). Each of the parameters may have several factors that are varied within the parameter space.

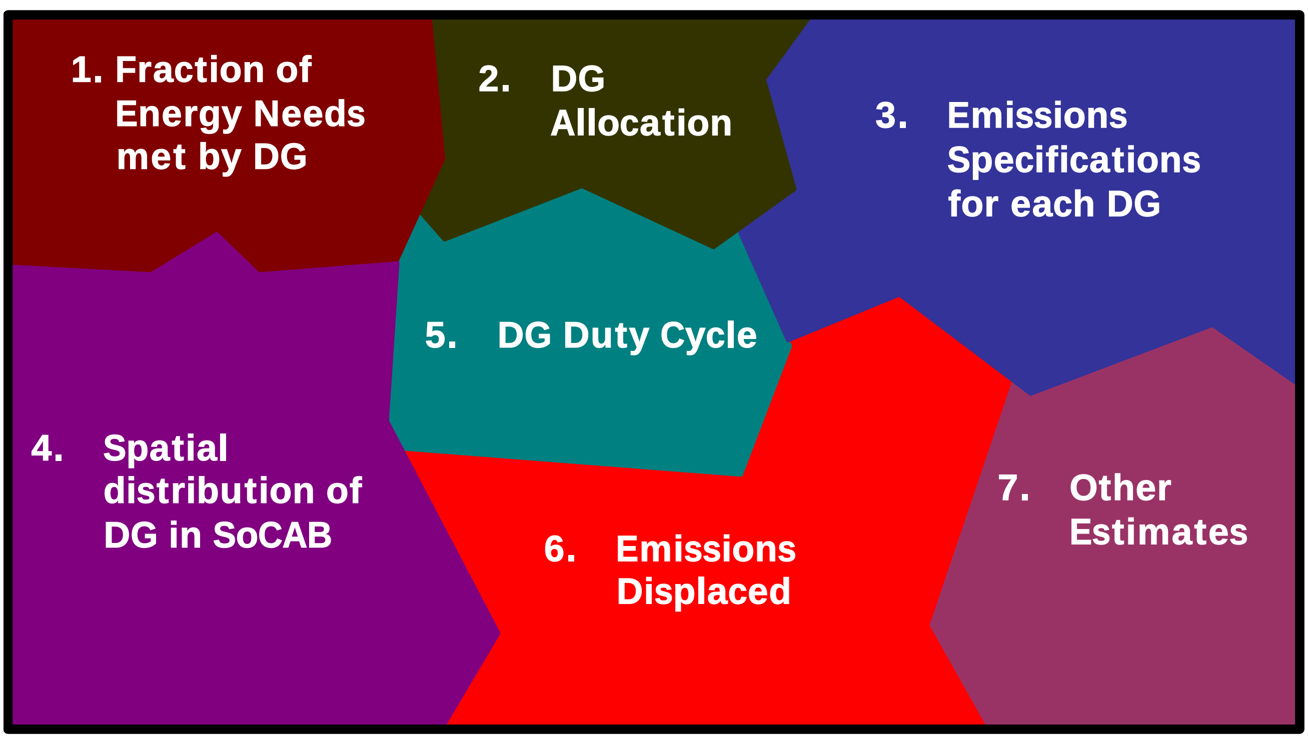


Figure 1: Schematic of the DG scenario parameter space.

Table 1 presents more details of the parameter space and all of the factors that are considered in the development of the DG scenarios. The overall outline of these parameters (highest level of characterization) and factors (lower level variables) is presented in Table 1 below. Note that we consider some of the parameters as fully characterized by variations in primary factors, whereas other parameters require characterizations and variation of primary and secondary factors in their definition.

Table 1. List of parameters and factors that are required to be characterized to represent a full distributed generation scenario for the South Coast Air Basin.

Main DG Parameter	Primary Factors	Secondary Factors
1. Fraction of energy needs met by DG	1.1. Limited (5% of increase)	
	1.2. Medium (10% of increase)	
	1.3. High (15-20% of increase)	
2. DG allocation	2.1. Types of DG units	2.1.1. All NG large GT-DG (50 MW)
		2.1.2. Fuel Cell Only
		2.1.3. MTG only
		2.1.4. Renewables – yes, no
		2.1.5. Mix of DG (MTG, FC, NG-ICE, Stirling, hybrid, …)
		2.1.6. Mix of DG and large GT-DG (50 MW)
		2.1.7. Diesel included – yes or no
	2.2. Number of DG units of each type	2.2.1. Large DG unit size vs. small DG unit size
		2.2.2. Technology Mix Factors - High penetration of low emissions technologies (strong regulation/policy drivers) - Low penetration of low emissions technologies (either modest regulation or lack of technology advancement) - Zoning or land-use - Economic factors
3. Emissions specification for each DG	3.1. Current emissions factors	3.1.1. Known emissions factors – literature, data
		3.1.2. Estimated emissions factors
	3.2. Future advancements to meet regulatory requirements	3.2.1. Fraction that meets 2003 standards
		3.2.2. Fraction that meets 2007 standards
4. Spatial distribution of DG in SoCAB	4.1. Even	
	4.2. Population weighted	
	4.3. Population growth weighted	

	4.4. Land-use weighted	4.4.1. Classify Land-use
		4.4.2. Land-use energy adoption rate factors
		4.4.3. Land-use weighted technology adoption factors
	4.5. Electrical use weighted (need data from SCE/LADWP)	
	4.6. Freeway weighted	
5. DG duty cycle	5.1. Base-loaded	
	5.2. Peaking	
	5.3. Mix of base-loaded and peaking	
6. Emissions displaced	6.1. Port Emissions	NOTE: only if DG is installed in place of idling ships
	6.2. Landfill/digester/other flared or wasted gas use	NOTE: most of these sources have already implemented emissions mitigation technology
	6.3. CHP	6.3.1. Displace old boilers and equipment
		6.3.2. Displace new boilers and equipment
		6.3.3. Percentage of CHP value recovered
	6.4. In-Basin electricity emissions displaced	
7. Other estimates	7.1. Emissions assumptions	7.1.1. Speciation of total hydrocarbons into specific hydrocarbon compounds and particulate matter (PM) into 8 size classes and 19 species of PM
	7.2. Performance degradation (yes or no)	
	7.3. Geometrical features (elevated emissions – yes or no)	
	7.4. DG Commercial Adoption Rate	7.4.1. High Early Adoption (logarithmic increase of cumulative DG Power from 2003 to 2010)
		7.4.2. Low Early Adoption (exponential increase of cumulative DG power)
		7.4.3. Medium Early Adoption (linear increase of cumulative DG power)

Once all of the parameters and factors of Table 1 are specified, the DG scenario is fully characterized and the corresponding DG emissions inventory for each of the discrete cells in the computational model can be developed for each instance in time. The model calculates the transport, chemical reaction, diffusion, etc. of all the species within the basin on an hourly averaged basis. As a result, DG emissions rates must be specified for as listed in Table 1 for each cell and for each of the 24 hours of each day of the simulation. This DG emissions inventory is then formatted as a model input file and added to the baseline emissions inventory for use in the model to assess the air quality impacts of the DG emissions. The baseline emissions inventory includes the emissions forecasted for 2010 by the California Air Resources Board (CARB) and South Coast Air Quality Management District (SCAQMD) (Allen, 2002).

Note that two types of DG Scenarios are developed in the current effort as follows:

- "Realistic" DG Implementation Scenarios, and
- "Spanning" DG Implementation Scenarios.

These two categories segregate the DG Scenarios on the basis of the "likelihood" of the scenario. "Realistic" implementation scenarios for DG in the South Coast Air Basin are assessed by the APEP team and stakeholders who participated in the September 19, 2002 and May 20, 2003 workshops to be likely instances of DG installation in the SoCAB. However, for scientific completeness, for sensitivity analyses, and for determination of potential impacts for unexpected outcomes "Spanning" scenarios are required. These spanning scenarios must not be considered realistic or probable. The spanning DG scenarios are not expected and are only used for purposes of garnering insights that may be useful.

2.1 Fraction of Energy Met by DG

The "Fraction of Energy Met by DG" parameter has a strong influence in the final air quality impact that a DG scenario exhibits. A high penetration scenario implies that DG units throughout the basin meet a considerable portion of the total energy needs of the SoCAB. In this case, DG emissions significantly contribute to the total SoCAB pollutant emissions. However, for the same level of emissions, air quality impacts might be very different depending on other DG scenario characterization parameters such as spatial distribution of the DG power or duty cycle. In addition, these impacts are not easy to predict without a detailed and comprehensive model due to the highly non-linear processes that govern the coupled transport and atmospheric chemistry of an air basin.

According to the California Energy Commission Strategic Plan for DG (Tomashefsky and Marks 2002), the forecasted adoption of DG in California for the year 2020 could be as high as 20% of the electricity load growth. The current DG scenarios are considered high penetration scenarios if the power demand met by DG is greater than 15% of the increased SoCAB power. Medium and low penetration are assigned to cases with about 10% and 5%, respectively, of the increased power demands met by DG.

Since the fraction of energy met by DG is quite uncertain, a wide variety of DG penetration levels is investigated in the DG scenarios to span the spectrum of possible air quality impacts.

2.2 DG Allocation

Based on input from the first industry stakeholders workshop held in September 2002 (See Appendix A for full details and results from this workshop), the current study includes distributed generators with power capacities that range from a few kilowatts (kW) up to 50 megawatts (MW). The 50 MW limit on DG is selected due to the permitting construct of the

SoCAB. The DG technologies that are likely to be implemented in the SoCAB include commercial technologies (natural gas fired combustion turbines (up to 50 MW) and natural gas fired reciprocating internal combustion engines (ICE)), and emerging technologies (solar photovoltaics (PV), fuel cells (PEMFC, MCFC and SOFC), gas turbine fuel cell hybrids, natural gas fired micro-turbine generators (MTGs), and external combustion Stirling engines).

The specific mix of DG technologies that is likely to be installed in any one region of the SoCAB in 2010 is very difficult to forecast. The technology mix is dependent on the number and type of energy customers in that region as well as a host of other economic and regulatory variables (e.g. electricity prices, gas prices, DG incentives, transmission constraints, emissions standards, etc.) that exist in that particular zone.

Every market segment can be preferentially associated with specific DG technologies that are likely to be predominant, mainly because their capacity and features are best suited to the energy demands of that segment. For example, residential applications in the range 1-5 kW will likely favor fuel cells and photovoltaics; commercial and small industrial sectors, with capacities ranges of 25-500 kW are more suited for PV, MTGs, small ICEs and FCs; large commercial and institutional sectors, in the range of 500-2MW, will likely favor natural gas reciprocating engines and gas turbines; and finally the large institutional and industrial sectors with 2-50 MW capacity will be mainly served by gas turbines. This relationship between DG type and market sector, together with spatial distributions of such in SoCAB is used in some of the scenarios to estimate the distribution and duty cycle of technologies in each of the discretized cells of the model on the basis of land-use zoning classification data.

The DG scenarios developed in this effort are not based upon a detailed market penetration analysis for the various DG technologies in SoCAB, but rather upon studies that are currently available in the literature, APEP insights, and stakeholder feedback. The resources used include: (1) previous studies that determined a reasonable mix of technologies (e.g., Ianucci et al., 2000; Marnay et al., 2001), (2) input from the industry stakeholder workshops (see Appendix A and Appendix B), (3) current APEP understanding of technology features, (4) current penetration of certain technologies (e.g., MTGs), and (5) APEP intuition; engineering insight and/or brainstorming.

Diesel and petroleum distillate fueled units are not included in the current mix of DG technologies since the SCAQMD does not currently permit them to run on a continual basis as distributed generators. These types of units are only permitted to run as back-up generators.

2.3 Spatial distribution of DG in SoCAB

It is important to capture the spatial distribution of emissions in an air basin in order to accurately determine species concentrations that contribute to air quality. The location of the emissions, together with meteorology, mass transport, photochemical reaction times, and the mixture of chemical compounds (both gases and aerosols), radiation intensity, etc. all contribute to the eventual air quality prediction (e.g., ozone, NOx, PM_{10} concentrations). To accurately estimate the spatial distribution of DG adoption, a detailed market penetration study should be conducted at the scale of model resolution. However, this is beyond the scope of the current study, so reasonable estimates of DG power in 2010 are developed based strictly upon demographic and economic parameters that can be correlated to power (e.g., population data, population growth data, electricity consumption data, land-use data, etc.). In most of the DG scenarios developed in this effort (spanning scenarios), the forecast of DG power in each cell is proportional to the number of inhabitants forecasted for 2010 in that cell, i.e., the DG spatial distribution is population weighted. The other spatial distributions that are applied in this study are:

- Even,
- Population growth weighted,
- Land-use weighted (used for all of the realistic scenarios),
- Electrical use weighted (based on available data from SCE and LADWP), and
- Freeway weighted.

2.4 DG Duty Cycle

The DG duty cycle parameter accounts for the temporal variation of DG power production that leads to the overall capacity factor (# of hours operating/total hours) for each of the individual DG devices. The actual duty cycle for an individual DG unit depends upon maintenance schedules, economics, power demand, and many other factors. For a specific scenario some DG technologies (e.g. high temperature fuel cells) will likely operate as base-loaded devices, i.e., they will operate essentially continuously. This is due to both economic (high efficiency and high capital cost portend continuous operation for reasonable payback) and operational factors (high temperature operation leads to long start-up, and high thermal stresses associated with transients). On the other hand, many other DG types are expected to operate primarily during peak hours. The combined DG duty cycle of all DG units operating in each cell results in a different set of pollutant emissions for each hour of the simulation. The air quality impacts of this duty cycle can be assessed by the air quality model, which is capable of accepting DG emissions profiles that vary on an hourly basis.

2.5 Emissions Specifications

There is a wide range of emissions factors that are either available as measured data or estimated by various investigators for each of the DG technologies. Some DG technologies are environmentally friendly, with zero emissions (e.g., wind turbines, photovoltaics) or near zero emissions (e.g., fuel cell systems), while others may emit more pollutants than central station power plants. For the some of the spanning DG scenarios the emissions factors proposed by Allison et al. (2002), which are best estimates from a compilation of sources, have been used directly. This data set, however, includes emissions factors are higher than the current regulated limits for DG units, some permitted by SCAQMD (ICEs and GT) and the others certified by ARB (MG, FC, Stirling engines, and others with less than 1 MW capacity). Whenever this occurred, the values selected to characterize a specific DG unit were the applicable standards levels instead of the emissions factors of Allison et al. (2002). The emissions factors proposed by Allison et al. (2002) for a collection of gas-driven DG technologies are presented in Table 2.

Table 2: Emissions Factors and Efficiencies for some DG technologies (after Allison and Lents, 2002)

Generation Type	Efficiency	CO	VOC	NOx	SOx	PM2.5	CO_2
	Elec. Out / Energy In	lbs/kWh	lbs/kWh	lbs/kWh	lbs/kWh	lbs/kWh	lbs/kWh
Gas Turbine Combined Cycle - central	0.52	1.70E-04	1.10E-04	1.30E-04	2.00E-05	2.00E-05	0.62
MTG	0.27	2.85E-03	5.00E-05	1.40E-03	2.00E-05	9.00E-05	1.25
Advanced Turbine	0.36	2.60E-03	3.00E-05	1.09E-03	2.00E-05	7.00E-05	0.95
Conventional Turbine	0.28	1.51E-03	4.00E-05	1.24E-03	3.00E-05	9.00E-05	1.2
Gas Powered ICE	0.35	8.00E-03	1.70E-03	3.20E-03	1.00E-05	4.75E-04	0.97
Diesel ICE	0.44	3.00E-02	2.00E-03	1.70E-02	3.00E-04	3.00E-03	1.7
PEM Fuel Cell	0.36	0.00E+00	9.00E-04	2.00E-05	1.00E-05	0.00E+00	0.95
Direct Fuel Cell	0.4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.68

For the realistic scenarios and to determine a more likely set of emissions for each of the DG technology types, the current study conducted an extensive literature search. This literature search, together with insights, reports, and feedback from agencies, industries, and colleagues has led the compilation of various emissions estimates as presented in Table 3. Six primary sources are presented in Table 3 with each of the DG technologies that are covered by each reference, and a listing of the pollutant species emissions rates that are available in each study.

Appendix C presents the details of emissions rates represented by the sources listed in Table 3. One should note that there is wide variability of emissions factors amongst the studies that are currently available. Also presented in Appendix C are the DG emissions standards for 2003 and 2007 and the current BACT requirements of SCAQMD for DG in the SoCAB.

Table 3: DG technologies and pollutant species available in 6 literature references for DG emissions factors.

Generation Type	NREL, 2003,	Nexus, 2002	Allison and Lents, UCR, 2002	Regulatory Assistant Project (RAP), 2001	Marnay et al., LBNL, 2001	Ianucci et al., DUA, 2000
Gas Turbine Combined Cycle - central	N/A	N/A	✓ CO, VOC, NO_x, SO_x, PM, CO_2	✓ CO, VOC, NO_x, SO_x, PM, CO_2	N/A	N/A
Microturbine Generator	✓ CO, NO_x, VOC, CO_2	✓ CO, NO_x, VOC	✓ CO, VOC, NO_x, SO_x, PM, CO_2	✓ CO, VOC, NO_x, SO_x, PM, CO_2	✓ CO, NO_x, PM	✓ CO, VOC, NO_x, SO_x, PM, CO_2
Advanced Turbine	N/A	✓ CO, NO_x, VOC	✓ CO, VOC, NO_x, SO_x, PM, CO_2	✓ CO, VOC, NO_x, SO_x, PM, CO_2	N/A	✓ CO, VOC, NO_x, SO_x, PM, CO_2
Conventional Turbine	N/A	✓ CO, NO_x, VOC	✓ CO, VOC, NO_x, SO_x, PM, CO_2	✓ CO, VOC, NO_x, SO_x, PM, CO_2	N/A	✓ CO, VOC, NO_x, SO_x, PM, CO_2
Uncontrolled Gas Powered Lean Burn ICE	N/A	N/A	✓ CO, VOC, NO_x, SO_x, PM, CO_2	✓ CO, VOC, NO_x, SO_x, PM, CO_2	✓ CO, NO_x, PM	✓ CO, VOC, NO_x, SO_x, PM, CO_2
Uncontrolled Diesel ICE	N/A	N/A	✓ CO, VOC, NO_x, SO_x, PM, CO_2	✓ CO, VOC, NO_x, SO_x, PM, CO_2	✓ CO, NO_x, PM	✓ CO, VOC, NO_x, SO_x, PM, CO_2
PEMFC	N/A	✓ CO, NO_x, VOC	✓ CO, VOC, NO_x, SO_x, PM, CO_2	N/A	N/A	✓ CO, VOC, NO_x, SO_x, PM, CO_2
DFC	N/A	✓ CO, NO_x, VOC	✓ CO, VOC, NO_x, SO_x, PM, CO_2	N/A	N/A	N/A
SOFC	N/A	✓ CO, NO_x, VOC	N/A	✓ NO_x, SO_x, PM, CO_2	N/A	N/A
3-way Catalyst Gas Powered Rich Burn ICE	N/A	✓ CO, NO_x, VOC	N/A	✓ CO, VOC, NO_x, SO_x, PM, CO_2	N/A	N/A
SCR Controlled Diesel ICE	N/A	✓ CO, NO_x, VOC	N/A	✓ CO, VOC, NO_x, SO_x, PM, CO_2	N/A	N/A

Appendix C presents plots for emissions rates of different DG technologies for the main 6 air pollutants (CO, NOx, VOC, SOx, PM, and CO_2). Minimum, maximum and average values of emissions estimates from all of the 6 literature sources presented in Table 3 are presented in Appendix C.

Table 4 and Table 5 present the recently approved California Air Resources Board emission standards (CO, VOC, NOx and PM limits) for type certification of DG. These standards apply to

DG units that do not fall under the jurisdiction of SCAQMD for control of stationary point sources. The capacity limit for SCAQMD rules to apply is 1MW, below which the regulatory requirements presented in Table 4 and Table 5 apply.

The SCAQMD best available control technology (BACT) permitted levels for DG emissions are presented in Table 6. The current project expended significant effort to study both the regulatory requirements of Table 4, Table 5, and Table 6 and all of the emissions estimates presented in Appendix C. This effort proved that significant disparities in the emissions rates and DG performance expectations exist, which adds uncertainty to the evaluation of DG environmental impacts. To address these disparities, the current project includes a sensitivity analyses effort that will determine model output sensitivities to emissions rates as well as search out measurements and verifiable performance data to include in the analyses. At the same time, the best possible estimates that are deemed reasonable and feasible and that do not violate current regulations are used in the scenario development of the current study.

In a couple of the spanning scenarios, DG emissions limits as currently set by ARB for 2003 and 2007, as well as SCAQMD best available control technology (BACT) standards for DG are used directly for all of the DG implemented. These spanning scenarios are presented as reference cases only.

Table 4: Approved ARB DG emissions standards for 2003 (Chin et al., 2001)

Pollutant / DG type	CO	VOC	NOx	PM
	lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh
DG Unit not integrated with Combined Heat and Power	6.00	1.00	0.50	An emission limit corresponding to natural gas with sulfur content of no more than 1 grain 100 standard cubic feet (scf)
DG Unit integrated with Combined Heat and Power	6.00	1.00	0.70	An emission limit corresponding to natural gas with sulfur content of no more than 1 grain 100 standard cubic feet (scf)

Table 5: Approved ARB DG emissions standards for 2007 (Chin et al. 2001)

Pollutant / DG type	CO	VOC	NOx	PM
	lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh
Emissions	0.100	0.020	0.070	An emission limit corresponding to natural gas with sulfur content of no more than 1 grain 100 standard cubic feet (scf)

Table 6: SCAQMD BACT guidelines for gas turbines and internal combustion engines (SCAQMD 2000)

Subcategory	VOC	NOx	SOx	CO	PM_{10}	Inorganic (NH_3)
NG GT, < 3 MWe						
ppm@15% O_2	**2**	**9**	--	**10**	--	**9**
lbs/MMBtu	0.0026	0.0332	**0.0008**	0.0224	**0.0066**	0.012
lbs/MW-hr	0.0358	0.4638	0.0112	0.3137	0.0923189	0.170
NG GT, ³ 3 MWe and < 50 MWe						
ppm@15% O_2	**2**	**3.6**	--	**10**	--	**5**
lbs/MMBtu	0.0026	0.0133	**0.0008**	0.0224	**0.0066**	0.007
lbs/MW-hr	0.0243	0.1257	0.0076	0.2126	0.0626	0.064
Non-Emergency NG ICE, < 2064 bhp						
ppm@15% O_2	32.42	11.28	--	74.18	--	--
lbs/MMBtu	0.0415	0.0415	**0.0008**	0.1663	**0.0066**	--
grams/bhp-hr	**0.15**	**0.15**	0.003	**0.600**	0.024	--
lbs/MW-hr	0.4431	0.4431	0.0085	1.7723	0.0704	--

Using the compilation of literature emissions factor data and the ARB and SCAQMD limits presented in Table 4, Table 5, and Table 6 as an upper bound, we have constructed two tables with emissions factors for DG systems installed in the periods 2003-2006 and 2007-2010, respectively, as shown in Table 7 and Table 8. These sets of DG emission factors are the ones utilized in the development of DG implementation scenarios, both the spanning and the realistic scenarios, unless otherwise specified.

Table 7: Emissions factors used to develop DG Scenarios in the current study for DG units installed in the period 2003-2006.

Generation Type	Efficiency (based on HHV)	CO	VOC	NOx	SOx	PM	CO_2	NH_3
		lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh
MTG	0.24	2.85E-03	5.00E-05	7.00E-04	1.01E-05	8.35E-05	1.50	0E+00
GT (<3 MW)	0.244	3.12E-04	3.58E-05	4.62E-04	1.12E-05	9.23E-05	1.66	1.70E-04
GT (>3 MW)	0.36	2.12E-04	2.43E-05	1.26E-04	7.59E-06	6.26E-05	1.13	6.42E-05
Gas ICE	0.32	1.77E-03	4.43E-04	4.43E-04	8.54E-06	7.04E-05	1.27	0.E+00
LT FC	0.36	1.00E-04	9.00E-04	7.00E-05	7.59E-06	6.26E-05	1.16	0.E+00
HT FC	0.48	1.00E-04	2.00E-05	7.00E-05	5.69E-06	4.69E-05	0.85	0.E+00
Stirling	0.27	6.00E-03	1.00E-03	5.00E-04	1.01E-05	8.35E-05	1.50	0.E+00
Hybrid	0.7	6.00E-03	1.00E-03	5.00E-04	3.90E-06	3.22E-05	0.58	0.E+00

Table 8: Emissions factors used to develop DG Scenarios in the current study for DG units installed in the period 2007-2010.

Generation Type	Efficiency (based on HHV)	CO	VOC	NOx	SOx	PM	CO_2	NH_3
		lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh
MTG	0.24	1.00E-04	2.00E-05	7.00E-05	1.01E-05	8.35E-05	1.50	0.00E+00
GT (<3 MW)	0.244	3.12E-04	3.58E-05	4.62E-04	1.12E-05	9.23E-05	1.66	1.70E-04
GT (>3 MW)	0.36	2.12E-04	2.43E-05	1.26E-04	7.59E-06	6.26E-05	1.13	6.42E-05
Gas ICE	0.32	1.77E-03	4.43E-04	4.43E-04	8.54E-06	7.04E-05	1.27	0.00E+00
LT FC	0.36	1.00E-04	2.00E-05	7.00E-05	7.59E-06	6.26E-05	1.16	0.00E+00
HT FC	0.48	1.00E-04	2.00E-05	7.00E-05	5.69E-06	4.69E-05	0.85	0.00E+00
Stirling	0.27	1.00E-04	2.00E-05	7.00E-05	1.01E-05	8.35E-05	1.50	0.00E+00
Hybrid	0.7	1.00E-04	2.00E-05	7.00E-05	3.90E-06	3.22E-05	0.58	0.00E+00

The emissions factors presented in Table 7 and Table 8 indicate that the DG technologies that can be deployed in the SoCAB have relatively low criteria pollutant emissions rates (i.e., they are clean DG technologies). Nonetheless, if DG are widely adopted in the SoCAB, the contribution of DG emissions compared to total emissions estimates in the SoCAB for 2010 is important enough to be concerned about potential air quality impacts of DG deployment. For example, one of the spanning scenarios, characterized by an extremely high penetration (20% of total power met by DG) and a mix of DG technologies, produces DG NOx emissions that account for 2% of total SoCAB NOx emissions inventory for 2010.

Figure 2 presents a comparison of DG criteria pollutant emissions (carbon monoxide, nitrogen oxides, reactive organic gases, and particulate matter) and the total basin emissions inventory for the SoCAB in 2010. The data of Figure 2 represent the non-attainment emissions inventory (i.e., one that scales emissions for population and vehicle miles traveled growth and assumes no additional regulatory measures are adopted (SCAQMD, 2003)) compared to the high DG penetration scenario described above. Note that the DG NOx contribution could be as large as 6% of the total NOx emissions in the SoCAB if compared with an attainment inventory for 2010.

Even though the realistic DG scenarios typically contain lower DG penetration and result in much smaller contributions of DG emissions to the inventory, the air quality impacts of these DG emissions may still be significant. First, many particular locations in the SoCAB are “on the edge” between compliance and non-compliance. Even a 1 ppb change in ozone concentrations in one location, for example, could result in the basin not achieving attainment. In addition, since the coupled transport and atmospheric chemistry interactions are of a highly non-linear nature small changes in emissions fields could lead to substantial air quality impacts.

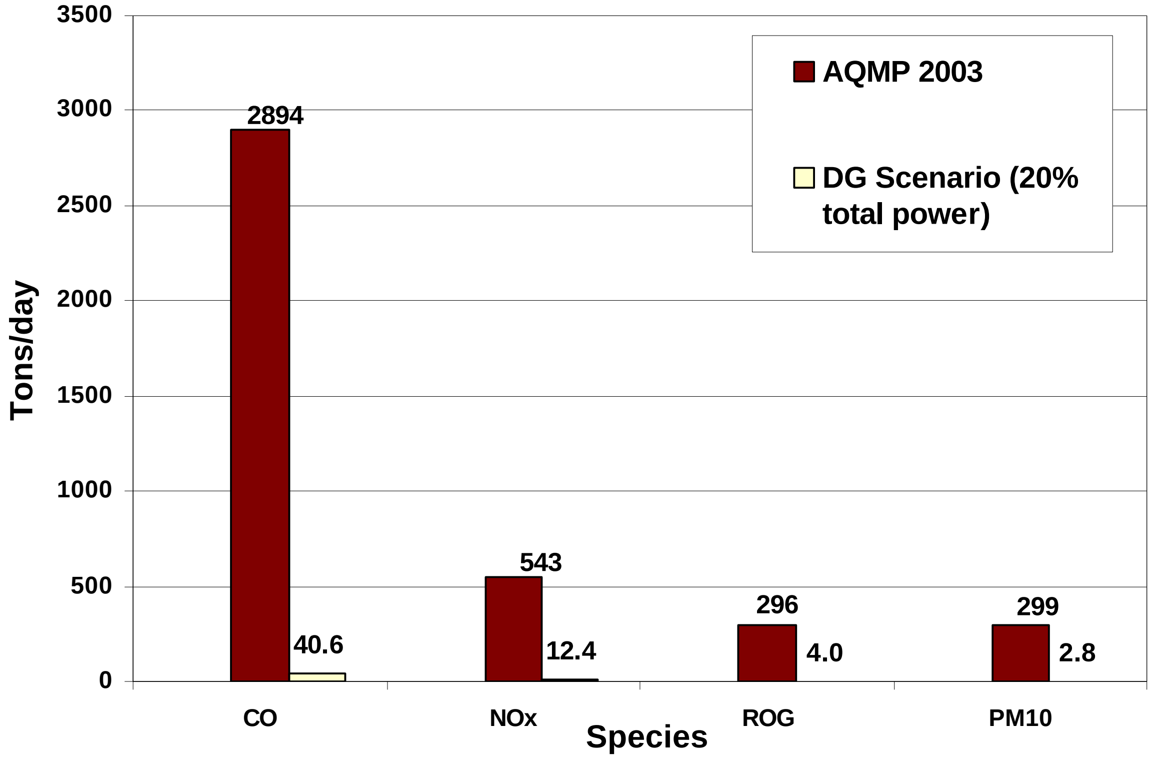


Figure 2: Comparison of total SoCAB emissions in 2010 and DG emissions from an extremely high DG penetration scenario.

2.6 Emissions Displaced

Many of the DG technologies that are being and will be adopted in the SoCAB will be used in combined heating cooling and power (CHP) applications because the higher overall energy efficiency of CHP improves the economics of certain DG projects. Waste heat produced during electricity generation can be captured by a heat recovery system that provides useful heat to meet facility thermal loads, which can significantly decrease operating costs. As a result, DG/CHP can replace the heat produced by burning fuel in a boiler leading to a reduction (displacement) of boiler-associated emissions in the basin. For retrofit DG/CHP applications, old, more polluting boilers are likely to be displaced, whereas for new applications displacement of emissions from new equipment (i.e., more efficient and lower polluting boilers) should be considered.

Emissions into the SoCAB can also be displaced by application of DG to waste gases from solid landfills, oil fields, or biomass gas emissions (e.g., dairy farm gaseous emissions). In these cases the DG application displaces either direct hydrocarbon emissions or flared gas emissions depending upon the current status of the waste gas emission. According to Lents et al. (2002), all DG units in this type of application reduce ozone related emissions compared to a central station combined cycle power plant. Due to this fact and due to encouragement from the SCAQMD, most of the landfills in the SoCAB have already implemented DG (Lenssen, 2001) to substitute for flares and produce on-site power and heat.

Other DG applications in which emissions could be displaced include the replacing of old central power plants in the basin and the substitution of lower emitting DG technologies for the diesel generators that are extensively used in Los Angeles port and vicinity. All of the above potential displacements of emissions are taken into account in the development of realistic DG scenarios.

2.6.1 CHP emissions displacement

To assess the displaced boiler emissions and net DG emissions for each of the discretized model cells in scenarios in which CHP emissions displacement is considered, the following procedure is applied:

1. Estimate a reasonable share of DG implemented in the SoCAB that is installed with waste heat recovery equipment (e.g., f_{CHP} = 60% was suggested in the stakeholder workshop).
2. Assume an average heat recovery utilization factor or heat recovery capacity factor, which includes the lost waste heat due to supply and demand mismatch (e.g., f_{HR} = 50%).
3. Evaluate the total amount of thermal heat recovered in each hour, Q_{HR}, taking into account the electric energy produced by the DGs, Q_{elec}, the electrical and total efficiencies of each fuel-driven DG technology, $h_{elec,i}$ and $h_{total,i,}$, respectively, and the particular mix of DG, $f_{DG,i}$, which can vary hour by hour due to possible differences in duty cycle for each technology.

$$Q_{HR} = Q_{elec} \sum_{i}^{n} \left(f_{DG_i} \frac{\left(h_{total\,i} - h_{elec\,i}\right)}{h_{elec_i}} \right) \cdot f_{CHP} \cdot f_{HR} \qquad (1)$$

4. Assume a reasonable mix of old, inefficient, dirty boilers (associated with retrofit DG/CHP) and new, clean, more efficient boilers (associated with new DG/CHP projects). Example: f_{old} = 30%: f_{new} = 70%.
5. Evaluate the total amount of offset fuel that would otherwise be burnt in the boilers to produce the same quantity of thermal energy delivered by the DG/CHP units. Consider both old boilers and new boilers efficiencies (e.g.: ef_{old} = 0.8 and ef_{new} = 0.9).

$$Q_{fuel} = \frac{Q_{HR}}{\left(ef_{old}\, f_{old} + ef_{new}\, f_{new}\right)} \qquad (2)$$

6. Use both emissions factors for old (em_{old}) and new boilers (em_{new}) and calculate the avoided emissions in each cell. As an example, the expression for displaced boiler CO emissions is presented below:

$$M_{CO,off} = Q_{fuel}\left(em_{old,CO}\, f_{old} + em_{new,CO} ef_{new}\right) \qquad (3)$$

7. Determine the net flux of emissions for each pollutant in a cell due to DG, subtracting the displaced boiler emissions from the total DG emissions contribution. In the case of CO, the net DG emissions can be written as follows:

$$M_{CO,net} = M_{CO,DG} - M_{CO,off} \qquad (4)$$

2.6.2 Emissions factors for boilers

New and old SCAQMD values for avoidable boiler air emissions are presented in Table 9. The avoided emissions per kWh of electric generation for a particular DG-CHP technology can be written as:

$$DGHeatRate(Btu_{in} / kwh_e) \cdot \frac{(ef_{tot} - ef_{elec})}{ef_{boiler}} \cdot f_{boiler}(lbs / Btu) \qquad (5)$$

Table 9: Typical boiler air emissions (Ianucci et al., 2000; Kay, 2003)

	CO lbs/MMBtu	**VOC** lbs/MMBtu	**NOx** lbs/MMBtu	**SOx** lbs/MMBtu	**$PM_{2.5}$** lbs/MMBtu	**CO_2** lbs/MMBtu
New	2.35E-02	5.39E-03	1.5E-02	5.90E-04	7.45E-03	118
Old	8.24E-02	5.39E-03	3.6E-02	5.90E-04	7.45E-03	118

2.6.3 Analysis of maximum potential emissions displacement for each DG technology

This section assesses the reduction in emissions for four representative DG technologies in the case when the heat recovery unit is running continuously, 24 hours a day and is fully utilized. This case represents the maximum theoretical emissions displacement, when both the share of CHP and the heat recovery capacity factor are equal to 100 %. Therefore, this exercise gives an upper bond of emissions offsets that DG implementation scenarios would be able to provide if all DG installations included CHP. Table 10 shows CO, VOC, NO_x and CO_2 emissions reductions when CHP is applied to 4 DG types (fuel cells, natural gas ICEs, diesel ICEs and MTGs). Boiler emissions displacements both for new and retrofit applications are presented in Table 10.

Table 10: Maximum emission displacements for 4 types of DG-CHP units

Type of DG	**Type of applica-tion**	**CO**			**VOC**			**NOx**			**CO_2**		
		DG (lbs/kWh)	**Boiler** (lbs/kWh)	**% Red.**	**DG** (lbs/kWh)	**Boiler** (lbs/kWh)	**% Red.**	**DG** (lbs/kWh)	**Boiler** (lbs/kWh)	**% Red.**	**DG** (lbs/kWh)	**Boiler** (lbs/kWh)	**% Red.**
Fuel cell (PEM)	Retrofit	0.0001	0.00048	**478.4%**	0.0009	3.1E-05	**3.5%**	7E-05	0.00021	**298.6%**	1.16	0.685	**59.1%**
	New	0.0001	0.00012	**121.2%**	0.0009	2.8E-05	**3.1%**	7E-05	7.7E-5	**110.6%**	1.16	0.609	**52.5%**
Natural gas ICE	Retrofit	0.0018	0.00058	**32.2%**	0.00044	3.8E-05	**8.6%**	0.00044	0.00025	**57.3%**	1.27	0.834	**65.6%**
	New	0.0018	0.000148	**8.3%**	0.00044	3.4E-05	**8.6%**	0.00044	9.4E-5	**21.2%**	1.27	0.741	**58.3%**
Diesel ICE	Retrofit	0.0077	0.00033	**4.3%**	0.0014	2.1E-05	**1.5%**	0.013	0.00014	**1.1%**	1.3	0.469	**63.9%**
	New	0.0077	8.3E-05	**1.1%**	0.0014	1.9E-05	**1.4%**	0.013	5.3E-5	**0.4%**	1.3	0.417	**32.1%**
MTG	Retrofit	0.00285	0.00076	**26.5%**	0.00005	4.9E-05	**98.8%**	0.0007	0.00033	**47.12%**	1.5	1.081	**72.1%**
	New	0.00285	0.00019	**6.7%**	0.00005	4.4E-05	**87.8%**	0.0007	0.00012	**17.45%**	1.5	0.961	**64.1%**

Note that for natural gas and diesel ICEs, with higher pollutant emission footprints (see Allison and Lents (2002) for ICE emissions and Table 7 for the other DG emissions), boiler emission displacements are not very high (0-32 %). The only exception is the 57.3% reduction in NO_x emissions for a natural gas ICE displacing an old boiler. On the other hand, when cleaner fuel driven DG such as MTGs or fuel cells are considered, significant reductions are achieved, resulting in some cases in a negative net emissions flux (e.g. NO_x emissions for fuel cells with CHP). Furthermore, all natural gas driven CHP technologies yield to significant displacement (52-72% reduction) of global warming CO_2 emissions.

In realistic DG scenarios, where all the above DG-CHP technologies are included in different shares and heat recovery capacity factors will be significantly less than 100%, only small reductions in air pollutant emissions in the range 0-20% are expected. On the other hand, reductions in CO_2 emissions may be higher, in the range of 20-40 %.

2.7 Other Estimates

As some of the DG technologies are just emerging in the marketplace, certain features of these technologies, including accurate pollutant emissions rates and emissions speciation, are not readily available. In addition, understanding of features such as continuous versus peak power applicability, size of equipment, availability of fuel, emissions stack height, etc. may need to be estimated for the current study. Currently our group is carrying out a detailed emissions measurement process for various DG types in a DG testing facility, which is being used to complete some of the missing data. When data are still not available, however, reasonable estimates or assumptions are applied only as they required for compatibility with the simulation software.

One significant factor that must be estimated for the current study is the degradation rate for technologies installed in the earlier years between now and the study year of interest. All DG technologies experience some degradation in efficiency performance and many may also degrade in the pollutant emissions performance. Scarce data is available for accurate accounting of DG vintage as it pertains to degradation in performance – so that degradation must be estimated. The adoption cumulative curve of DG power in the following year is also uncertain and various curves (exponential, linear, etc.) are considered. Finally, some technologies are expected to substantially improve their emissions and efficiency performance over the next several years. This improvement in performance must also be estimated for accurate development of a DG scenario.

2.8 Speciation of criteria pollutants

To make the emissions fluxes from any DG scenario compatible with the input required by the air quality model, one must provide emissions fluxes for all species that the model currently considers in its detailed chemical mechanism. As a result, the total DG emissions of some criteria pollutants (NOx, SOx, VOC, and PM) must be split into a representative distribution of their constituent species. Table 11 shows the speciation and weighting factors used for each of the species for which this procedure was required. The codes presented in Table 11 for the species in VOC and PM are the same as those used in CACM chemical mechanism. The chemical name associated with each code is listed in Table 12.

Table 11: Speciation used for criteria pollutants from DG scenarios

Criteria Pollutant	Species							Comments
NOx	**NO**			**NO_2**				APEP estimates
% Weight	95%			5%				
SOx	**SO_2**			**SO_3**				APEP estimates
% Weight	95%			5%				
VOC	**CH_4**	**HCHO**	**ALKL**	**AROH**		**AROL**		VOC Speciation from ARB data for gas external combustion boiler profile (http://www.arb.ca.gov/emisinv/speciate/speciate.htm)
% Weight	58%	8%	29%	4%		2%		
PM	**EC**	**OC**	**Cl**	**Sf**	**Nt**	**K**	**Ca**	PM Speciation from ARB data for gas ICE profile (http://www.arb.ca.gov/emisinv/speciate/speciate.htm)
% Weight	20%	26%	7%	45%	1%	1%	1%	

Table 12: Chemical names for species considered in VOC and PM CACM speciation

Species	Species ID in CACM	Chemical Name	Criteria Pollutant
HCHO	4	Formaldehyde	VOC
ALKL	10	C2-C6 Alkanes	VOC
AROH	19	High Yield Aromatics	VOC
AROL	20	Low Yield Aromatics	VOC
EC	29	Elemental Carbon	PM
OC	30	Unresolved Organic Carbon	PM
Cl	32	Chloride ion	PM
Sf	34	Sulfur (VI)	PM
Nt	35	Nitrate	PM
K	37	Potassium	PM
Ca	38	Calcium	PM

2.8.1 Low early adoption of DG power

In all spanning scenarios except #S5 HEAPW20%, a realistic low early adoption of DG power is assumed. This implies that the curve of the annual rate of DG power adoption over the period 2003-2010 increases each year (exponentially or parabolic) until the DG power estimated for 2010 is achieved. Quantitatively, this means that only about 2% of the total DG power adopted in the period 2003-2010 will be implemented before 2007. For the remaining 98% of DG power that will be installed after 2007, those small units under the ARB certification program will have to meet the more stringent 2007 ARB emissions limits (see Table 5).

2.9 Performance degradation and geometrical features

Only one of the spanning scenarios accounts for performance degradation of the DG units. This spanning scenario includes a decrease of efficiency and an increase in emissions that occurs over the years with all of the DG units. The emissions degradation is allowed to proceed for all DG units up to the applicable regulatory requirement. The remainder of the spanning scenarios assume no degradation. Moreover, all of the scenarios included in the present study consider DG emissions to occur at ground level (i.e., no elevated emissions). A small number of DG may be installed on rooftops of tall buildings, but, this fact is not included in the DG scenarios.

2.10 Scenarios that include Emissions Displacement from in-basin Power Plants

The approach used to develop DG emissions inventories for scenarios that include emissions displacement from in-basin power plants is as follows:

1. Randomly locate one or more power plants in the SoCAB with approximately the same amount of power as the estimated DG power implemented for 2010 (1060 GW when 20% of the increased demand is met by DG). The database consulted is the one available in the website of the California Energy Commission for power plants in California (CEC, 2001). Two combustion turbine/steam turbine power plants situated in Long Beach and Huntington Beach with a total aggregated online capacity of 1090 GW were selected for the 20% of increased demand case, for example. The main characteristics of these plants are presented below in Table 13.

Table 13: Main characteristics of selected power plants in the SoCAB

Name	Address	Primary fuel	Technology	Online capacity (MW)	Cogen	Date Online	Type
Long Beach	2665 SEASIDE BLVD., LONG BEACH, CA 91770	NATURAL GAS	COMBUSTION TURBINE, STEAM TURBINE	530	NO	1/1/1976	Base loaded
Huntington Beach	21730 NEWLAND ST., HUNTINGTON BEACH, CA 92646	NATURAL Gas, DISTILLATE	STEAM TURBINE, COMBUSTION TURBINE	563	NO	6/1/1958	Base loaded

2. Determine the most recent emissions flux rates for each of the selected power plants from ARB website (ARB, 2000). Continuing with the same example, the values for criteria pollutant emissions from the Long Beach and Huntington Beach power plants in 2000 are shown below in Table 14.

Table 14: Emissions from selected power plants in the SoCAB

Name	Year	CO (tons/year)	NOx (tons/year)	VOC (tons/year)	SOx (tons/year)	PM (tons/year)	NH_3 (tons/year)
Long Beach	2000	80.8	159	366.8	0.5	10.8	-
Huntington Beach	2000	56.5	290.7	39.7	2.8	9.2	0.18

3. Identify the model cells where the power plants are installed. For this purpose we used the web map tool developed in the first stages of this project (see Appendix D), which allows the user to click in any particular point in a SoCAB map and get the air quality model coordinates as well as the UTM coordinates of that point. In the case of the current example, the X and Y model coordinates for Huntington Beach and Long Beach power plants are (41,10) and (35,12), respectively.
4. Determine the power plants emissions in the suitable units of the model. To do that, we have assumed a capacity factor for both power plants of 80%, a reasonable value for base loaded power plants.
5. Evaluate the net emissions from the DG scenario in each cell of the computational domain. The only cells that have different emissions from the ones in Scenario #S1 are precisely those cells with displaced emissions from the power plants. For the current example, the 2 cells that represent Huntignton Beach and Long Beach power plants contain negative emissions fluxes in the DG scenario because emissions from the power plants is significantly higher than the emissions from the DG units implemented in those same cells. However total emissions of this scenario plus the baseline emissions are still positive.

2.11 Business As Usual DG Scenario Development

To develop a “business as usual” scenario, one can assume a linear extrapolation of DG power and DG mix from the current trends in the SoCAB area as documented in the years 2001 and 2002. Data for current trends of DG power in California under 1 MW were extracted from the Self-Generation Incentive Program Second Year report (CPUC, 2003). Table 15 shows the evolution of active programs in terms of kW for the different incentive levels of the program.

Table 15: Active DG CPUC projects (in kW) in 2001 and 2002

Incentive Level	Total Active 2001 (kW)	Total Active 2002 (kW)
Level 1	2291	26875
Level 2	200	600
Level 3N	15452	57625
Level 3R	-	1585
Total	17943	86685

It was also roughly assumed that only the DG projects administered by Southern California Edison (SCE) and Southern California Gas Company (SoCal Gas) are to be implemented in the SoCAB, which accounts for 51% of the total DG power. For the other large electricity company in the SoCAB, the Los Angeles Department of Water and Power municipal utility (LADWP), no data on DG power installed under LADWP service territory is available. As a result, an assumption has been made that the total DG power installed in 2001 and 2002 in the LADWP service territory is 35% of that installed in SCE territory. This level of DG penetration directly corresponds to the ratio of LADWP to SCE power delivered in the SoCAB in 2002.

The distribution of power among the DG types under 1 MW is also based on the CPUC data for the business as usual cases. This leads to adoption of DG types as follows: 32% PV, 1.2% FC, 7.5% MTG, and 59.3% ICE. This DG mix is considered constant in the extrapolation of DG power up to 2010 for all business as usual cases. For the LAWDP DG power, we have estimated the same mix of DG types as that reported by SCE and SoCal Gas.

According to the installed peak power plants in the SoCAB in the last 2 years with less than 50 MW total capacity each (CEC, 2003), a constant increase of large gas turbines of 49 MW at a rate of 1 unit per year was assumed in this business as usual case. Entering this amount of DG power from large gas turbines into the DG mix mentioned above, and recalculated the distribution of DG types in 2010 thus leads to the following adoption rates, based on total power production, for the business as usual cases: 59% GT, 25% ICE 13% PV, 3% MTG, and 0.5% FC.

Figure 3 shows the projected linear trends for accumulated DG power in the period 2001-2010 based on real data in years 2001 and 2002. A total DG power capacity of 936 MW is projected for the year 2010, which requires a total installation of 680 MW additional DG capacity in the period 2003-2010.

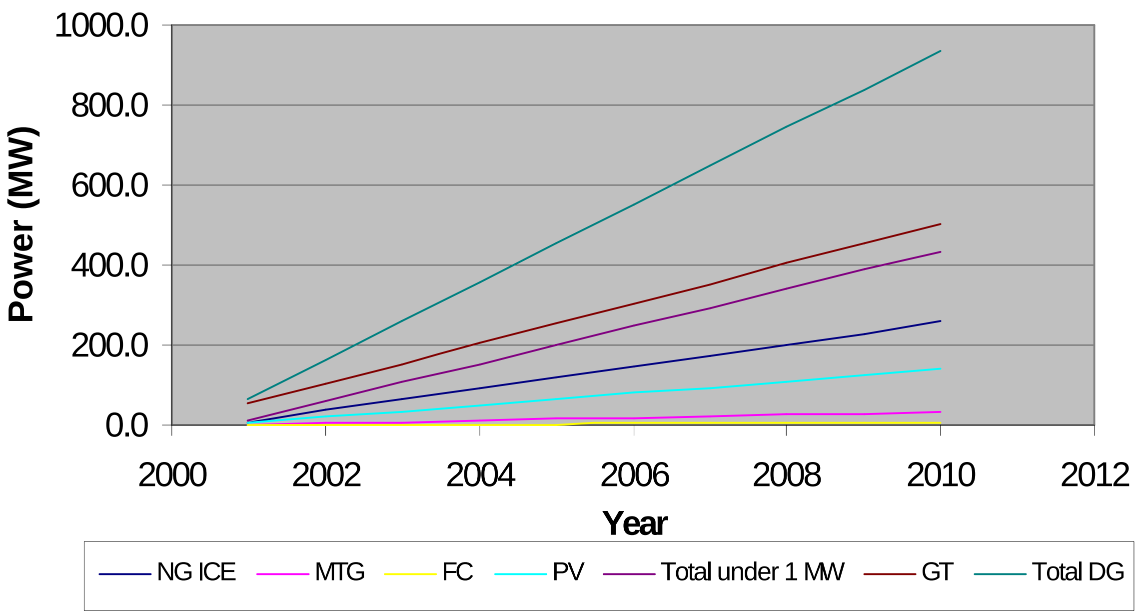


Figure 3: Projected DG power trends in the SoCAB according to CPUC Self-Generation Program DG data for 2001 and 2002 using a linear fit.

Alternatively, one could apply an increasing parabolic extrapolation of the DG power data of 2001 and 2002 instead of a linear extrapolation, by assuming zero DG power was installed in the year 2000. In this case, more DG power and more emissions from DG are expected. Projections of DG power for this case are shown in Figure 4. Note that this set of assumptions for DG adoption in the business as usual cases leads to a total installed capacity of DG that is almost 1800 MW in the year 2010.

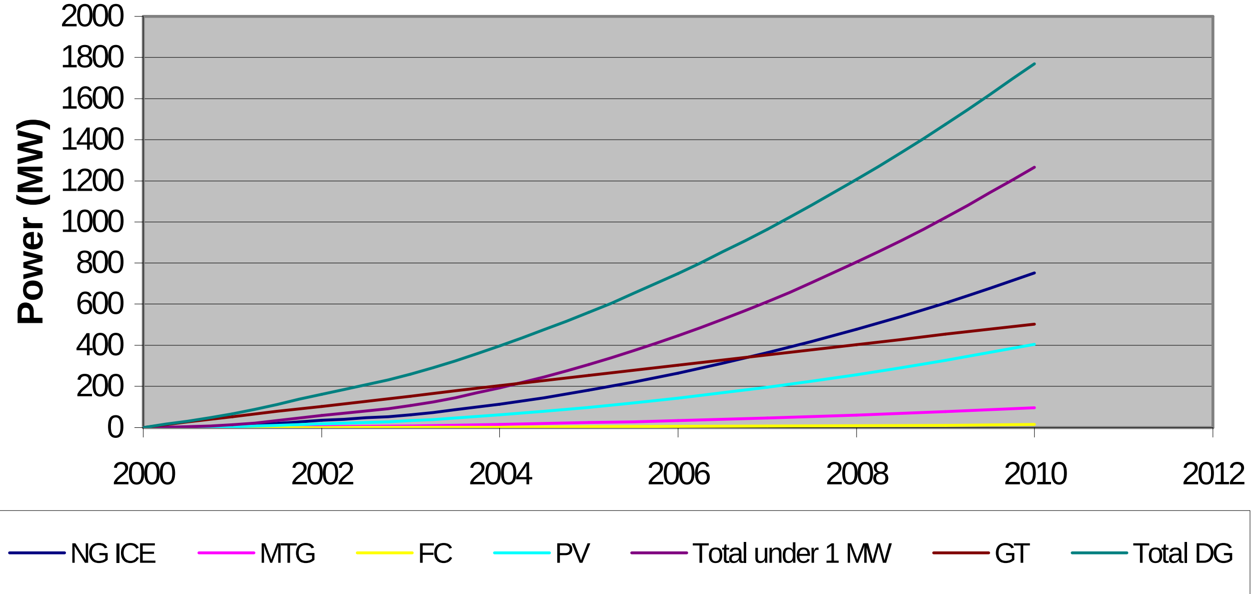


Figure 4: Projected DG power trends in the SoCAB according to CPUC Self-Generation Program DG data for 2001 and 2002 using a parabolic fit.

2.12 Summary of emissions from Spanning Scenarios

Figure 5 shows a comparison of criteria pollutant emissions rates resulting from the various DG spanning scenarios. As scenarios #S9 (PGW20%), #S10 (LUW20%), and #S11 (Free20) present exactly the same amount of total DG emissions but with a different spatial distribution, they are not all presented in the bar chart of Figure 5. One of the realistic scenarios, #R3 is included for comparison purposes. Note that the emissions flux rates are presented on a log scale. Presented in this manner one should observe that the differences in overall, basin-wide DG emissions amongst the various DG implementation scenarios are not orders of magnitude different. Most of the DG scenarios contain DG emissions rates that are within an order of magnitude of the typical emissions fluxes. Exceptions to this are the EHP case with significantly higher CO_2 emissions and the DGEED case with significantly lower CO_2 emissions.

The same DG scenario emissions results that are presented in Figure 5 are presented in Figure 6. In Figure 6, however, the scale on which emissions fluxes are plotted is linear (vs. the logarithmic scale of Figure 5). Notice that there are significant differences amongst the DG scenarios that are more obvious when the data are plotted on a linear scale.

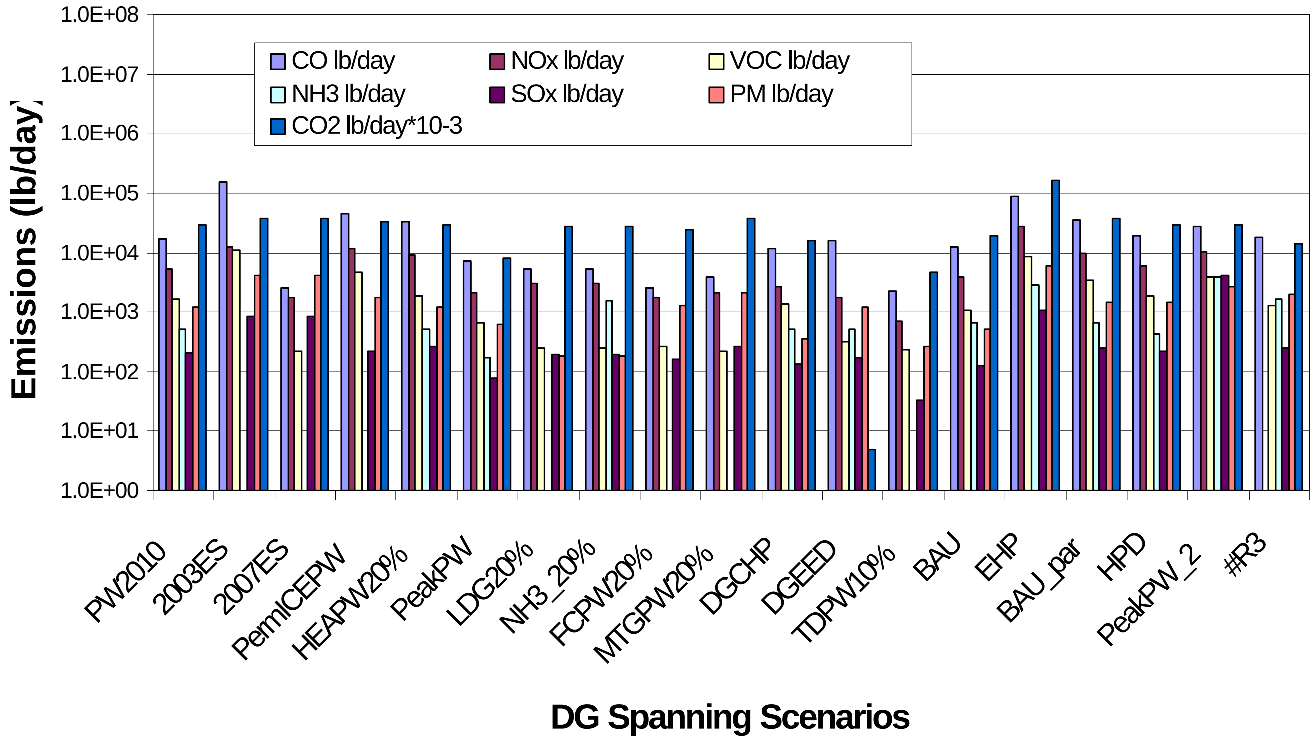


Figure 5: Comparison of criteria pollutant emissions among DG spanning scenarios (logarithmic scale).

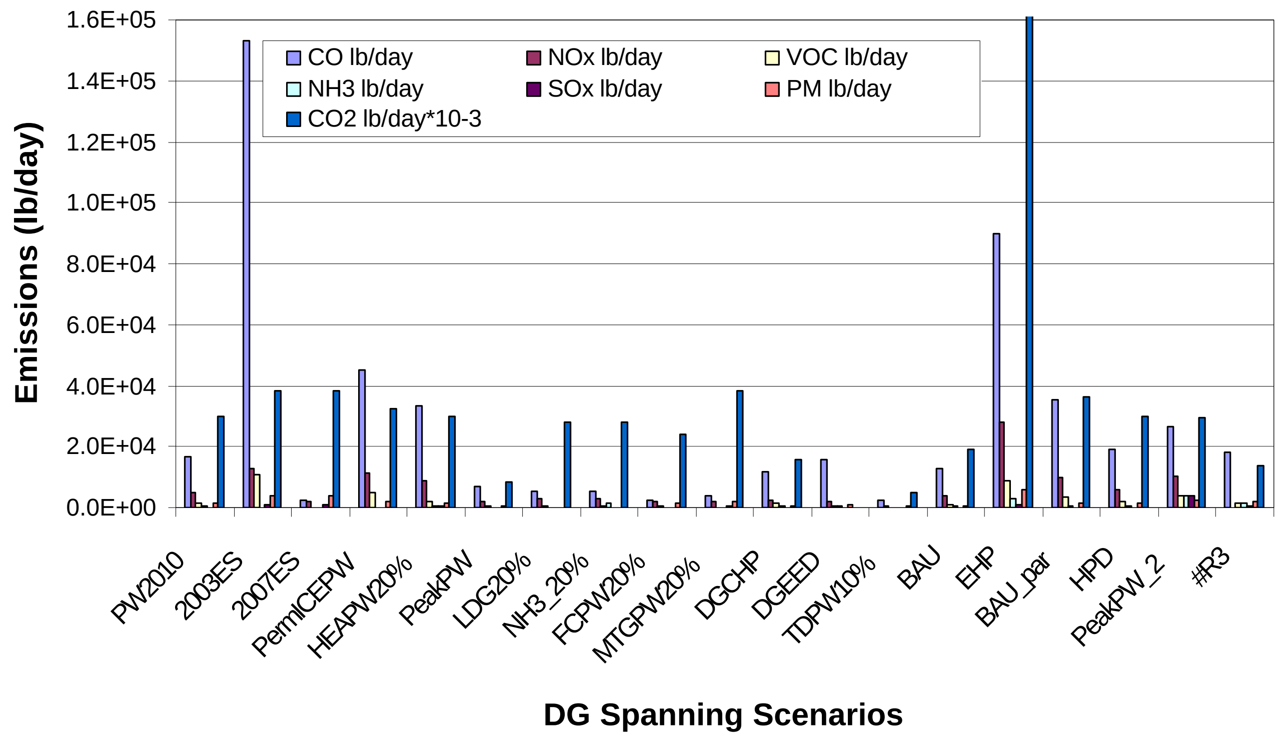


Figure 6. Comparison of criteria pollutant emissions among DG spanning scenarios (linear scale).

3 EXTRACTION AND PROCESSING OF GIS LAND-USE DATA

The use of a realistic means of defining the spatial distribution of DG in the SoCAB is critically important to the realistic prediction of air quality impact. In addition, the first industry stakeholder workshop strongly recommended spatial allocation of the DG technologies throughout the basin according the actual electrical and thermal demand anticipated for 2010 and the type of end-use for each spatial location. The sort of information required to accomplish this is only available from special sources. These sources include the local utilities, which have spatially resolved data on electricity consumption, and local governmental agencies that have global information systems (GIS) information for the SoCAB.

Thanks to the generous donation of the organization Southern California Area Governments (SCAG), the team was provided access to GIS land-use data for the following counties: Los Angeles, Orange, San Bernardino, Riverside, Imperial and Ventura. The latest data in this GIS data set were collected in the year 2000. Figure 7 shows how the computational domain of the air quality model for the SoCAB includes partially or wholly the counties of Orange, Los Angeles, Riverside, San Bernardino and Ventura.

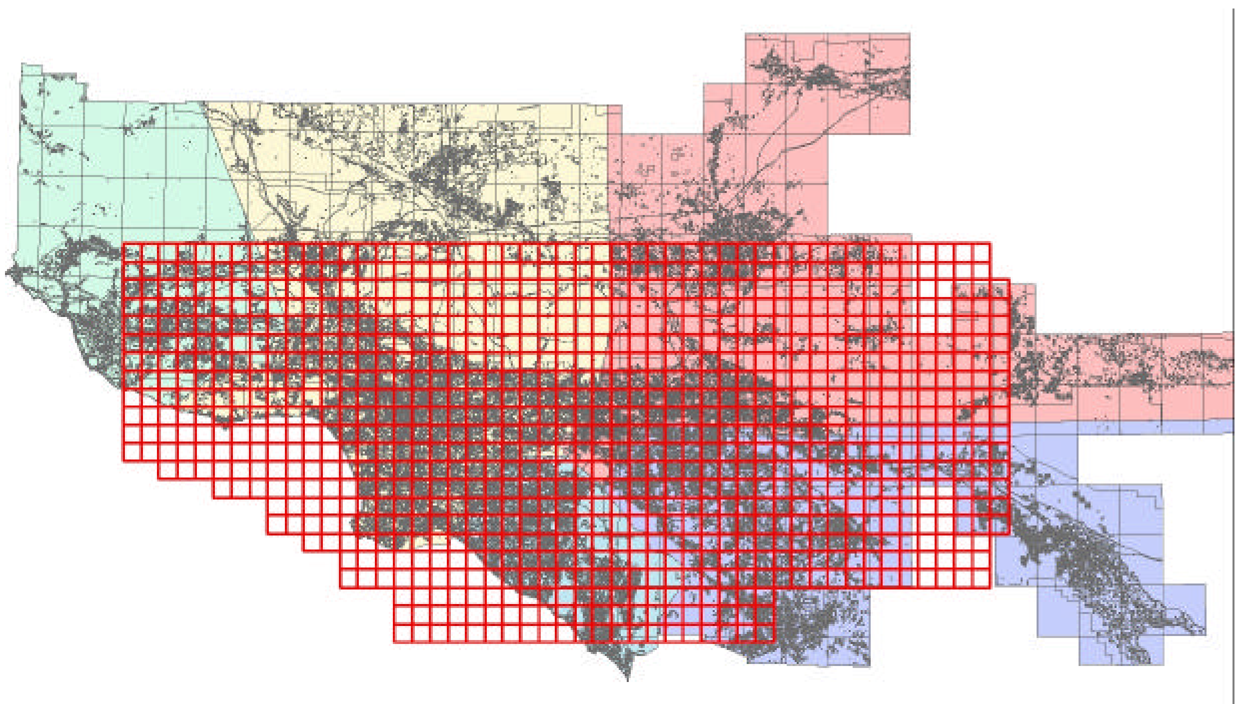


Figure 7: Southern California Counties with land-use GIS data and the computational grid of the air quality model (in red lines).

These data consist of each of the counties divided into land parcels (polygons) of different area and shape. The number of parcels per county is rather large. For example the total number of individual land parcels in LA County alone is more than 40,000. The land parcels have a resolution of 2 acres (0.0081 km^2). Each of the polygons has associated with it a database that contains an ID number, total area, and zone classification code. Figure 8 presents a picture of a small region near Long Beach to illustrate the typical number and resolution of the land parcel polygons. The location of the 5 km x 5 km model cells and corresponding resolution of the air quality model in this same region are represented by the red lines of Figure 8.

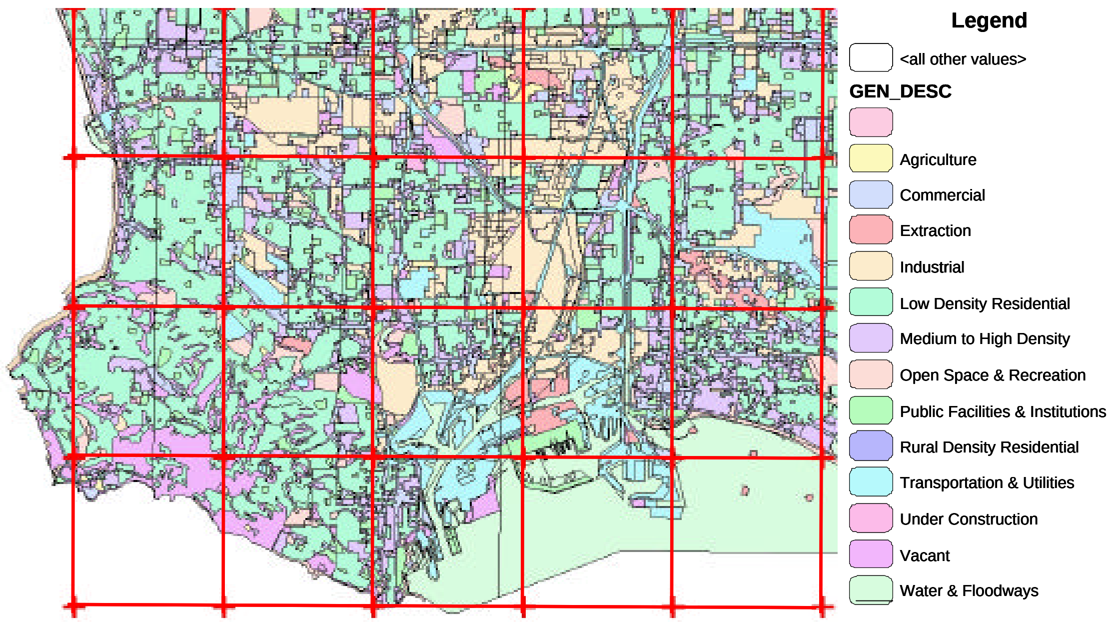


Figure 8: Example of generic land-uses in Long Beach area.

The GIS database contains 132 different specific land-use types that are aggregated into 13 generic land use types. The 13 generic land use types are the only types presented in Figure 8. Table 16, on the other hand, shows both the specific land-use types and the generic types that are contained in the GIS database.

Table 16: Land-use codes and descriptions

LU CODE	LAND USE DESCRIPTION	GENERIC LAND USE TYPE
1000	Urban or Built-Up	
1100	Residential	Low Density Residential
1110	Single Family Residential	Low Density Residential
1111	High Density Single Family Residential	Low Density Residential
1112	Low Density Single Family Residential	Low Density Residential
1120	Multi-Family Residential	Medium to High Density Residential
1121	Mixed Multi-Family Residential	Medium to High Density Residential
1122	Duplexes, Triplexes & 2 or 3 Unit Condos & Townhomes	Medium to High Density Residential
1123	Low-Rise Apartments Condominiums and Townhouses	Medium to High Density Residential
1124	Medium-Rise Apartments and Condominiums	Medium to High Density Residential
1125	High-Rise Apartments and Condominiums	Medium to High Density Residential
1130	Mobile Homes and Trailer Parks	Medium to High Density Residential
1131	Trailer Parks and Mobile Home Courts High Density	Medium to High Density Residential
1132	Mobile Home Courts and Subdivisions Low Density	Medium to High Density Residential

LU CODE	LAND USE DESCRIPTION	GENERIC LAND USE TYPE
1140	Mixed Residential	Medium to High Density Residential
1150	Rural Residential	Low Density Residential
1151	Rural Residential High Density	Low Density Residential
1152	Rural Residential Low Density	Rural Density Residential
1200	Commercial and Services	Commercial
1210	General Office Use	Commercial
1211	Low- and Medium-Rise Major Office Use	Commercial
1212	High-Rise Major Office Use	Commercial
1213	Skyscrapers	Commercial
1220	Retail Stores and Commercial Services	Commercial
1221	Regional Shopping Mall	Commercial
1222	Retail Centers, Non-Strip Contiguous Interconnected Off-Street	Commercial
1223	Modern Strip Development	Commercial
1224	Older Strip Development	Commercial
1230	Other Commercial	Commercial
1231	Commercial Storage	Commercial
1232	Commercial Recreation	Commercial
1233	Hotels and Motels	Commercial
1234	Attended Pay Public Parking Facilities	Commercial
1240	Public Facilities	Public Facilities & Institutions
1241	Government Offices	Public Facilities & Institutions
1242	Police and Sheriff Stations	Public Facilities & Institutions
1243	Fire Stations	Public Facilities & Institutions
1244	Major Medical Health Care Facilities	Public Facilities & Institutions
1245	Religious Facilities	Public Facilities & Institutions
1246	Other Public Facilities	Public Facilities & Institutions
1247	Non-Attended Public Parking Facilities	Public Facilities & Institutions
1250	Special Use Facilities	Public Facilities & Institutions
1251	Correctional Facilities	Public Facilities & Institutions
1252	Special Care Facilities	Public Facilities & Institutions
1253	Other Special Use Facilities	Public Facilities & Institutions
1260	Educational Institutions	Public Facilities & Institutions
1261	Pre-Schools Day Care Centers	Public Facilities & Institutions
1262	Elementary Schools	Public Facilities & Institutions
1263	Junior or Intermediate High Schools	Public Facilities & Institutions
1264	Senior High Schools	Public Facilities & Institutions
1265	Colleges and Universities	Public Facilities & Institutions
1266	Trade Schools	Public Facilities & Institutions
1270	Military Installations	Public Facilities & Institutions
1271	Base Built-up Area	Public Facilities & Institutions
1272	Vacant Area	Vacant
1273	Air Field	Public Facilities & Institutions
1300	Industrial	Industrial
1310	Light Industrial	Industrial
1311	Manufacturing Assembly and Industrial Services	Industrial
1312	Motion Picture and Television Studio Lots	Industrial
1313	Packing Houses and Grain Elevators	Industrial
1314	Research and Development	Industrial
1320	Heavy Industrial	Industrial
1321	Manufacturing	Industrial

LU CODE	LAND USE DESCRIPTION	GENERIC LAND USE TYPE
1322	Petroleum Refining and Processing	Industrial
1323	Open Storage	Industrial
1324	Major Metal Processing	Industrial
1325	Chemical Processing	Industrial
1330	Extraction	Extraction
1331	Mineral Extraction - Other Than Oil and Gas	Extraction
1332	Mineral Extraction - Oil and Gas	Extraction
1340	Wholesaling and Warehousing	Industrial
1400	Transportation Communications and Utilities	Transportation & Utilities
1410	Transportation	Transportation & Utilities
1411	Airports	Transportation & Utilities
1412	Railroads	Transportation & Utilities
1413	Freeways and Major Roads	Transportation & Utilities
1414	Park and Ride Lots	Transportation & Utilities
1415	Bus Terminals and Yards	Transportation & Utilities
1416	Truck Terminals	Transportation & Utilities
1417	Harbor Facilities	Transportation & Utilities
1418	Navigation Aids	Transportation & Utilities
1420	Communication Facilities	Transportation & Utilities
1430	Utility Facilities	Transportation & Utilities
1431	Electrical Power Facilities	Transportation & Utilities
1432	Solid Waste Disposal Facilities	Transportation & Utilities
1433	Liquid Waste Disposal Facilities	Transportation & Utilities
1434	Water Storage Facilities	Transportation & Utilities
1435	Natural Gas and Petroleum Facilities	Transportation & Utilities
1436	Water Transfer Facilities	Transportation & Utilities
1437	Improved Flood Waterways and Structures	Transportation & Utilities
1438	Mixed Wind Energy Generation and Percolation Basin	Transportation & Utilities
1440	Maintenance Yards	Transportation & Utilities
1450	Mixed Transportation	Transportation & Utilities
1460	Mixed Transportation and Utility	Transportation & Utilities
1500	Mixed Commercial and Industrial	Industrial
1600	Mixed Urban	Industrial
1700	Under Construction	Vacant
1800	Open Space and Recreation	Open Space & Recreation
1810	Golf Courses	Open Space & Recreation
1820	Local Parks and Recreation	Open Space & Recreation
1821	Local Park Developed	Open Space & Recreation
1822	Local Park Undeveloped	Open Space & Recreation
1830	Regional Parks and Recreation	Open Space & Recreation
1831	Regional Park Developed	Open Space & Recreation
1832	Regional Park Undeveloped	Open Space & Recreation
1840	Cemeteries	Open Space & Recreation
1850	Wildlife Preserves and Sanctuaries	Open Space & Recreation
1860	Specimen Gardens and Arboreta	Open Space & Recreation
1870	Beach Parks	Open Space & Recreation
1880	Other Open Space and Recreation	Open Space & Recreation
1900	Urban Vacant	Vacant
2000	Agriculture	Agriculture
2100	Cropland and Improved Pasture Land	Agriculture
2120	Non-Irrigated Cropland and Improved Pasture Land	Agriculture

LU CODE	LAND USE DESCRIPTION	GENERIC LAND USE TYPE
2200	Orchards and Vineyards	Agriculture
2300	Nurseries	Agriculture
2400	Dairy and Intensive Livestock	Agriculture
2500	Poultry Operations	Agriculture
2600	Other Agriculture	Agriculture
2700	Horse Ranches	Agriculture
3000	Vacant	Vacant
3100	Vacant Undifferentiated	Vacant
3200	Abandoned Orchards and Vineyards	Vacant
3300	Vacant With Limited Improvements	Vacant
3400	Beaches (Vacant)	Open Space & Recreation
4000	Water	Water & Floodways
4100	Water	Water & Floodways
4200	Harbor Water Facilities	Water & Floodways
4300	Marina Water Facilities	Water & Floodways
4400	Water Within a Military Installation	Water & Floodways
4500	Area of Inundation (High Water)	Water & Floodways

3.1 GIS data extraction

The first step required to make effective use of the land-use GIS data in our DG scenarios was to correlate (i.e., scale-up) the resolution of the GIS data with the 5 km x 5 km resolution of the air quality model grid. This task proved to be quite challenging, requiring the assistance of a skilled computer programmer with expertise in graphical data extraction. In this process, APEP staff were assisted by Tony Soeller, staff member of the Network and Academic Computing Services (NACS) at UCI, and an expert in GIS data management and manipulation.

After some weeks of intensive work, the APEP team, working with Tony Soeller, came up with a 15-step procedure that uses the GIS software ArcMap to satisfactorily map the GIS data to the air quality model grid. This strategy for integrating GIS data with the AQM is described in this section of the report.

Table 17 presents a small cross-section of the model grid as a sample of the type of data we now have available to use for all of the cells in the model. The *X* and *Y* coordinates of the model are presented in Table 17, followed by the square kilometers (km^2) of area within each cell that correspond to Agriculture, Commercial, Extraction, Industrial, Low Density Residential, etc. land use types. Issues that had to be resolved in the process of extracting GIS data included:

- How does one define and create the 5 x 5 km cell layer in GIS?
- How does one identify the location of each polygon with respect to the cells?
- How can one determine if land-use polygons are entirely inside one cell or shared amongst cells?
- How can one account for land-use polygons that occupy more than one cell?
- How the GIS data be exported in a convenient way to use in the Excel scenario development files?

All of these issues have been resolved to the satisfaction of the APEP team.

Table 17: Detail of some cells with GIS land-use data extracted

		Agriculture	Commercial	Extraction	Industrial	Low Density Residential	. . .
Ymodel	Xmodel	A_{Agric} km^2	A_{Comm} km^2	A_{Ext} km^2	A_{Ind} km^2	A_{Lowres} km^2	
26	19	1.335	0.000	0.549	0.000	0.031	
26	20	0.012	0.000	0.503	0.000	0.000	
26	21	0.175	0.000	0.000	0.000	0.000	
26	22	5.147	0.000	0.000	0.000	0.000	
26	23	0.043	0.000	0.026	0.000	0.000	
26	24	0.040	0.000	0.137	0.000	0.000	
26	25	1.453	0.000	0.136	0.000	0.000	
26	26	0.044	0.000	1.310	0.000	0.000	
26	27	0.545	0.000	1.116	0.000	0.586	
26	28	2.896	0.868	1.498	1.128	0.685	
26	29	3.212	0.151	0.000	1.520	4.766	
26	30	0.650	0.125	0.000	0.120	5.810	
26	31	0.180	0.319	0.000	0.173	1.779	
26	32	0.123	0.008	0.932	0.037	2.120	
26	33	0.028	0.000	0.388	0.000	0.000	
26	34	0.090	0.000	0.000	0.018	0.000	

. . .

In the process of extracting the GIS data, the APEP team isolated each of the 13 generic land-use categories. These generic land use categories are listed in Table 18. Reducing the total number of land use types to the 13 generic land use types allowed reasonable identification of the spatial distribution of land use types in the SoCAB. Maps with the locations of all the parcels belonging to each land-use types are presented in Appendix E.

Table 18. Generic Land Use Categories

LU CODES	GENERIC LAND USE TYPE
1000 – 1112, 1150 – 1151	Low Density Residential
1120 – 1140	Medium to High Density Residential
1152	Rural Density Residential
1200 – 1234	Commercial
1240 – 1273	Public Facilities & Institutions
1300 – 1325, 1340, 1500, 1600	Industrial
1330 – 1332	Extraction
1400 – 1460	Transportation & Utilities
1700, 1900, 3000, 3100, 3200, 3300	Vacant
1800 – 1880, 3400	Open Space & Recreation
2000 – 2700	Agriculture
4000 – 4500	Water & Floodways

Figure 9 presents a bar chart with the total areas for the 13 generic land-use categories. Note that the "Vacant" area is by far the largest land-use category with more area (greater than 12,000 km^2) associated with it than any other category. The vacant area is followed by the "Low Density Residential" land use category with about 3,000 km^2 in the SoCAB. The third and forth land-use categories with significant area in the SoCAB are "Agriculture" and "Transportation and Utilities", respectively. For perspective on the land-use categories with smaller total areas, Figure 10 presents the total areas for the 12 of the 13 generic land-use categories. All but the "Vacant" land-use category are presented in Figure 10.

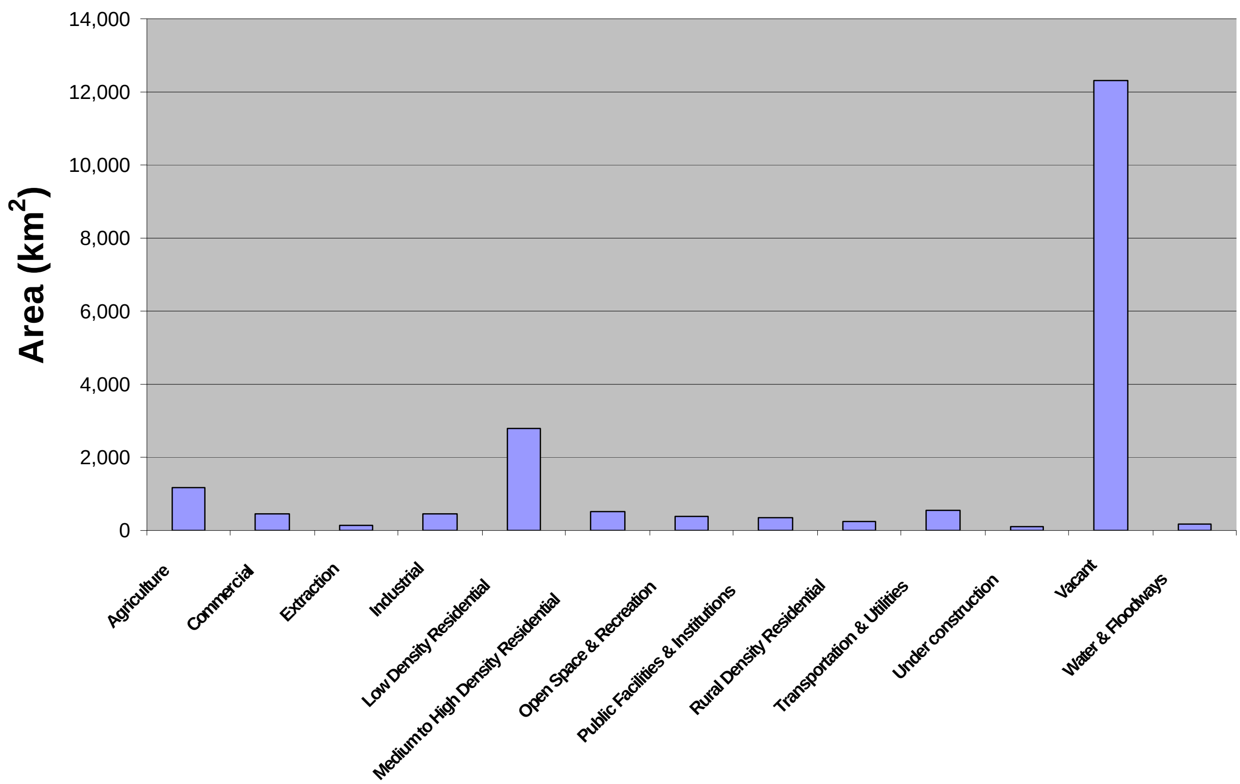


Figure 9: Total land-use areas in the 13 generic land use categories in SoCAB.

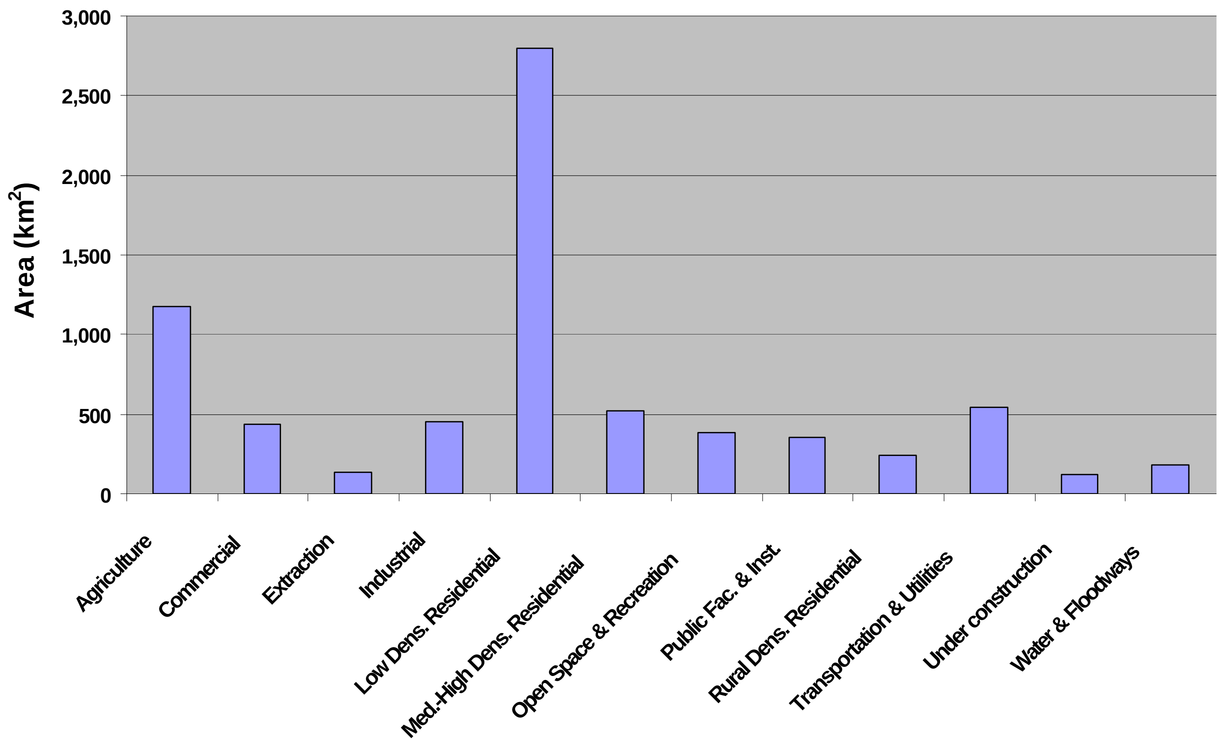


Figure 10. Total land-use areas in 12 of the 13 generic land use categories in SoCAB (Vacant category not plotted).

3.2 Approach to relate land-use data to DG power and DG mix

After extracting the areas in each cell for the 13 generic land-use categories, the next step was to design a strategy to relate land-use areas to the amount of DG power and to the mix of DG technologies assigned to each cell of the grid. Since the land-use categories generally refer to a sector of the economy that is expected to use DG (of various types and to varying degrees in various applications), the label used for groupings of land-use categories in this section is "sector."

A systematic approach to relate DG power and DG mix to land-use data has been developed that is well grounded in and fully based upon the most recent data and reports that are currently available. The approach presented herein was very well received by the stakeholders in the second Workshop (May 21, 2003), which was organized specifically to discuss the scenario development task and receive critique and feedback from DG stakeholders. Note that the approach presented herein is a comprehensive approach, but, one that is amenable to modification. We intend to include changes in the factors involved and are also open to considering and implementing refinements to the approach as new reports and data become available.

The systematic approach consists of a 10-step procedure that is described in this section of the report. The nomenclature used in the equations that define the approach is presented in Table 19 together with definitions for each variable.

Table 19: Nomenclature used in the equations that define the systematic approach for developing realistic DG scenarios

$A_{i,k}$	Area of sector *i* in cell *k*
$S_{i,j}$	Relative area of sector *i* in size category *j*
$A_{i,j,k}$	Area of sector *i* in size category *j* in cell *k*
A_{SoCAB}	Total Area in the SoCAB
$D_{i,h}$	Duty cycle factor in sector *i* and hour of the day *h*
$R_{i,j}$	Adoption rate relative intensity (in terms of DG power/square foot) for sector *i* in size category *j*
$F_{power,k}$	Factor accounting for the total DG power in each cell
$P_{Tot,k}$	Total DG power (in MW) assigned to each cell
$P_{Tot,SoCAB}$	Total DG power (in MW) estimated for the SoCAB in 2010
$P_{i,j,k}$	DG power (in MW) of specific sector *i* in size category *j* in cell *k*
$W_{l,i,j}$	Relative weight for DG type *l* in sector *i* and size category *j*
$T_{l,k}$	Relative contribution to DG power of DG type *l* in cell *k*
$P_{l,k}$	DG power (in MW) of DG type *l* in cell *k*
$e_{l,X}$	Emission factor for species *X* of DG type *l*
$[X]_{emiss,k}$	Total DG emissions of species *X* in cell *k*

In reading this section of the report one should periodically refer back to Table 19. Note that the subscript *i* refers to the sector type (i.e., groupings of land-use categories), the subscript *j* refers to the DG size class, and the subscript *k* refers to the AQM model cell. The subscript *h* refers to the hour of the day and the subscript *l* refers to the type of DG technology. These subscripts are consistent throughout the derivation presented in this section. Note that to develop a realistic DG implementation scenario, one must consider a large number of factors as shown in Table 19.

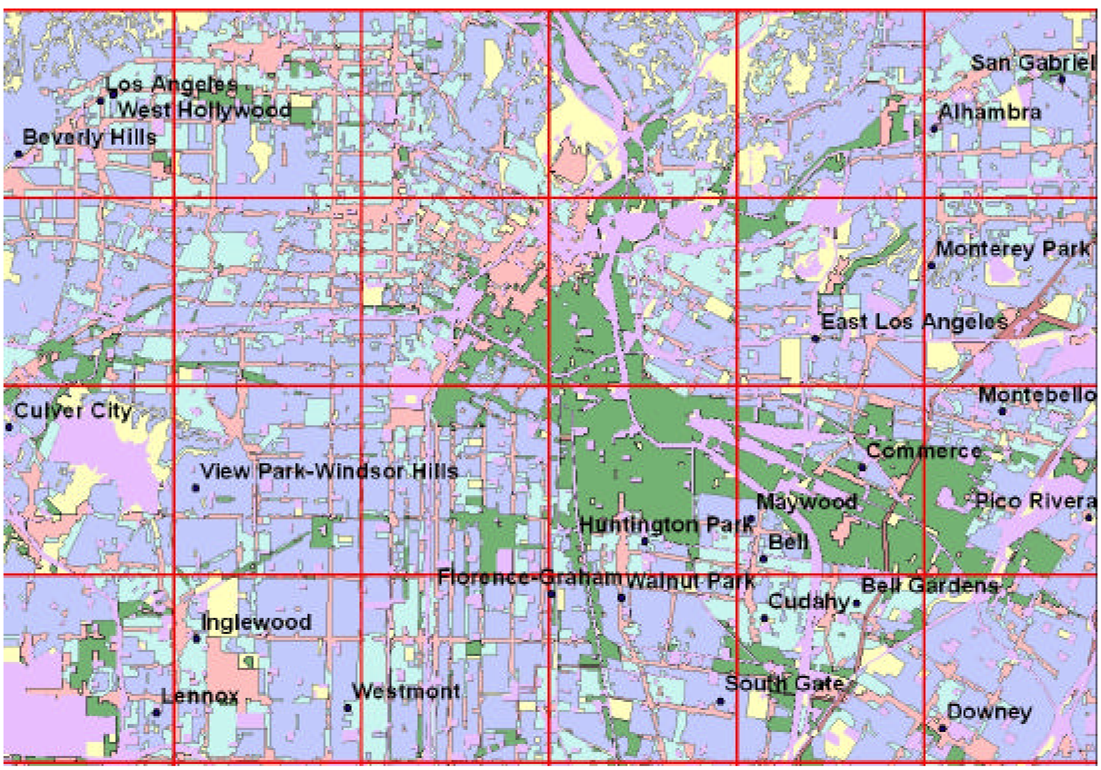
The development of a realistic scenario based on land-use data, DG size, DG type, and other available data and insights is presented in this section as a ten (10) step procedure. This process has been derived, honed and developed by the APEP team through many internal iterations and brainstorming sessions. This process has also been vetted by colleagues, California Energy Commission, SCAQMD, and ARB staff, and DG stakeholders who participated in the workshops (see Appendix A and B). The ten-step procedure is defined as follows.

STEP 1. The starting point for the DG scenario development is the extracted land-use data in 5x5 km resolution. These data consist of the areas (in square kilometers) of all 13 of the generic land use types for each of the 994 cells of the model grid. The 13 land use area types are aggregated into 6 different sectors (i.e., low density residential, medium-to-high density residential, commercial, industrial, agriculture, and others), as shown in Table 20. The amount of square kilometers of a sector type in any specific cell is represented by A_i. Figure 11 presents a representative picture of the aggregated GIS land-use categories as integrated into the six (6) economic sectors for the Central LA area.

Table 20: Integration of land-use types into energy sectors

Sector	Land use types considered in that sector *
Low Density Residential	***Low Density Residential***
	Rural Density Residential
Medium to High Density Residential	***Medium to High Density Residential***
Commercial	***Commercial***
Industrial	***Industrial***
Agriculture& Water Pumping	***Agriculture***
Other	***Extraction***
	Public Facilities & Institutions
	Transportation & Utilities
	Under Construction

**** The rest of the land use categories (Vacant, Water and Flood Ways, and Open Space and Recreation) assumed to adopt zero DG power***



Low Density Res. Medium to High Density Res. Industrial
Commercial Agriculture Others

Figure 11: Land use parcels in central LA aggregated into 6 energy sector categories

STEP 2. The second step is to disaggregate each of the sector areas in each cell into six (6) sub-categories according to DG size capacity. The six DG size classes that are used are:

- <50 kW,
- 50-250 kW,
- 250-1,000 kW,
- 1-5 MW,
- 5-20 MW, and
- 20-50 MW.

The bases of this disaggregating process are several reports on energy consumption surveys in the commercial, residential and manufacturing sectors by the Energy Information Agency (1999; 1999; 2000). These reports relate total floor space of various establishment types in each sector to the annual electricity consumption. From these data the average power demand for each establishment is estimated and the potential for each sector to adopt DG in each of the six size classes is determined. The results of these analyses are normalized by dividing the area of each size-category by the total area in that sector to get a relative area per sector (*i*) and per size category (*j*), which is represented by $S_{i,j}$. Two of the sectors (Agriculture and Other) required the development of estimated S_{ij} since no data is currently available for these sectors. Reasonable estimates were made based on the S_{ij} of the other sectors and insights of the APEP team. The equation that relates total area to area per size category for each of the sectors considered is:

$$A_{i,j,k} = S_{i,j} \cdot A_{i,k} \qquad (6)$$

Table 21 shows the resulting normalized area factors that are applied to disaggregate (split) the sectors (groups of GIS land-use areas) into specific areas for each DG size category.

Table 21: Normalized area factors for each DG size category for the different sectors.

Size category	Low Density Residential	Medium and high density residential	Commercial	Industrial	Agriculture	Other
< 50 kW	99%	95%	55%	0%	80%	0%
50-250 kW	1%	5%	17%	5%	10%	5%
250-1,000 kW	0%	0%	20%	15%	10%	15%
1-5 MW	0%	0%	8%	22%	0%	22%
5-20 MW	0%	0%	0%	30%	0%	30%
20-50 MW	0%	0%	0%	28%	0%	28%
Total	100%	100%	100%	100%	100%	100%

STEP 3. The third step is to determine DG power in each of the disaggregated (DG size class dependent) areas in each cell of the model based on a third factor included in this approach. This third factor is called the "Adoption Rate Relative Intensity" factor and has the units of DG power per square kilometer. This relative adoption rate intensity is a function of both the sector and the DG power size category, and is represented by $R_{i,j}$ in the current approach. The adoption rate relative intensity factor, $R_{i,j}$, accounts for the fact that a certain amount of land that is occupied by a certain economic sector will adopt DG technology at a rate that differs from that of other sectors.

The adoption rate relative intensity factor, $R_{i,j}$, are determined in the current approach as a function of both size category and sector based on a report that describes CHP penetration in the commercial and industrial sectors in California (CEC, 1999). Note that this report only provides combined market penetration of DG with CHP and includes both the industrial and the commercial sectors. The relative adoption rates for DG in other sectors are estimated from comparison to these data and APEP team insights. Table 22 presents the current estimates for those intensity factors. The factors should be interpreted as follows: if the DG power penetration in a square kilometer of the low density residential sector in the size category <50 kW is 1.6 MW, the corresponding DG power penetration in the same area for the industrial sector in the range capacity 20-50 MW is 567.2 MW. The adoption rate relative intensity factors of Table 22 are well grounded in the literature and APEP insights that are currently available. However, these factors can be refined and modified at any time as additional detailed market penetration studies are completed and as information becomes available for DG market penetration in California (especially in the SoCAB).

Table 22: Adoption Rate Relative Intensity per size category and per sector

Size category	Low Density Residential	Medium and high density residential	Commercial	Industrial	Agriculture	Other
< 50 kW	1.6	16.4	7.9	7.9	3.2	1.0
50-250 kW	8.3	208.1	151.7	151.7	8.6	19.1
250-1,000 kW	0.0	0.0	141.5	141.5	8.6	17.9
1-5 MW	0.0	0.0	221.5	221.5	0.0	27.9
5-20 MW	0.0	0.0	0.0	376.9	0.0	47.6
20-50 MW	0.0	0.0	0.0	567.2	0.0	71.6

As a result of the above development of areas and factors, one can determine the total DG power in each cell as a sum of the areas per sector and per size category ($A_{i,,j,k}$) multiplied by the adoption rate relative intensity. This factor F_{power} is determined for each individual cell of the air quality model as follows:

$$F_{power,k} = \sum_i \sum_j A_{i,j,k} R_{i,j} \qquad (7)$$

The total DG power in real units (MW) assigned to each cell *k* of the model is then determined as a function of the assumed total implementation of DG power in the SoCAB (portion of increased power demand met by DG) and the normalized power factor as follows:

$$P_{Tot,k} = \frac{F_{power,k}}{\sum_k F_{power,k}} \cdot P_{Tot,SoCAB} \qquad (8)$$

Once the total DG power in each cell is determined, DG power associated with each of the size categories in each sector can be described by the following equation:

$$P_{i,j,k} = \frac{A_{i,j} R_{i,j}}{F_{power}} P_{Tot,k} \qquad (9)$$

Finally then, the total DG power per sector and per cell can be written as:

$$P_{i,k} = \frac{\sum_j A_{i,j} R_{i,j}}{F_{power}} P_{Tot,k} \qquad (10)$$

STEP 4. At this point one must consider the operational duty cycle of DG units. The temporal variation of the DG power due to the variety of duty cycles of the units is introduced into this procedure as a function of the particular sector that the DG units are serving. Average load profiles are calculated for each sector based on hourly electric data obtained from the Southern California Edison web page (refer to Appendix F for details). To apply the sector specific duty cycle one must determine a normalized vector factor, $D_{i,h}$, which describes the hour-by-hour duty expected in each sector. The total power for a particular sector in a cell is presented in equation 10 as $P_{i,k}$. This factor is considered the peak DG power output that can occur at any one hour of the day in a particular sector. Thus, multiplying the normalized duty cycle by the peak sector power in each cell produces the total power per sector and per cell as a function of the time of the day as:

$$P_{i,k,h} = P_{i,k} D_{i,h} \qquad (11)$$

STEP 5. The next step consists of determining the relative contribution to total power in a cell by each of the DG types considered (namely, low temperature (LT) fuel cells, high temperature (HT) fuel cells, MTGs, NG ICEs, PV, conventional gas turbine (CGT), advanced gas turbine (AGT), Stirling engines, and Hybrid fuel cell systems). To accomplish this, 6 tables must be developed (one for each sector), in which the relative expected contribution of each DG type in each size category, $W_{l,j}$, is presented. Table 23 below presents the relative contributions of DG technology types ($W_{l,j}$) for the industrial sector as an example. The relative contribution factors all six (6) sectors are based on market penetration of DG technology types in the industrial sector (Little, 2000), utility sector (Ianucci et al., 2000), and building sector (Boedecker et al., 2000) and APEP team or other expert estimates on market distribution of DG technology types in each of the size categories.

Table 23: Estimated relative contributions of DG technology types in the Industrial sector as a function of size class.

Size categories	% LT Fuel cells	% HT Fuel cells	% MTGs	% NG ICEs	% PV	% CCT	% AGT	Stirling	Hybrid
< 50 kW	0.0%	0.3%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
50-250 kW	0.0%	2.1%	13.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
250-1,000 kW	0.0%	2.9%	0.0%	10.1%	0.0%	9.7%	0.0%	0.0%	2.5%
1-5 MW	0.0%	0.0%	0.0%	10.1%	0.0%	9.7%	0.0%	0.0%	2.5%
5-20 MW	0.0%	0.0%	0.0%	0.0%	0.0%	9.7%	13.0%	0.0%	0.0%
20-50 MW	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	13.0%	0.0%	0.0%
Total	0.0%	5.2%	14.4%	20.1%	0.0%	29.2%	26.0%	0.0%	5.0%

As a result, the equation that determines the relative contribution of each DG technology in each cell for a particular hour of the day, $T_{l,k,h}$, is given by:

$$T_{l,k,h} = \frac{\sum_i \sum_j W_{l,i,j,h} \cdot P_{i,j,k,h}}{P_{Tot,k,h}} \quad (12)$$

And the total DG power in each cell supplied for each of the DG types considered is:

$$P_{l,k,h} = T_{l,k,h} \cdot P_{Tot,k,h} \quad (13)$$

STEP 6. At this point an estimate of the spatial distribution of DG power and the mix of DG technologies in each cell of the model and the power that each is producing at each hour of the day has been determined. The sixth step to consider is a weighting factor for relative DG adoption rates that is a function of the location within the basin that one is considering. The systematic procedure presented thus far, uses average DG adoption factors for all cells throughout the basin. No local information on forecasted DG penetration in certain zones of the SoCAB due to any potential driver (e.g., transmission or distribution constraints in utility grid, strong DG incentives in particular cities, anticipated larger DG installations, etc.) has been included in the approach thus far.

Since data was not available to suggest preferential DG adoption at any particular location or set of locations in the SoCAB, the APEP team decided to retain average adoption rates. However, if at any time preferential DG adoption rates that apply to the spatial distribution of DG in the SoCAB become available one should apply a normalized adoption rate factor in this step. So far no local data is available and, therefore, no modification to the first five steps of this systematic approach is applied at this time in step six.

STEP 7. The seventh step is to calculate pollutant emissions in each cell and each hour of the day based on the emissions factors for each of the DG types, e_l. As explained in Section 2.5 Emissions Specifications, the emissions factors, e_l, for each of the DG types are determined from literature sources (Ianucci et al. 2000; Marnay et al. 2001; 2001; Allison and Lents 2002; 2002; 2003) and APEP measurements of emissions from various DG technologies. In all cases the emissions from DG within SoCAB are never allowed to exceed the applicable ARB and SCAQMD emissions limits. The emissions for all the DG pollutants considered in a given cell of the model can be determined through the following equations:

$$[CO]_{emiss,k,h} = \sum_l P_{l,k,h} \cdot e_{l,CO} \tag{14}$$

$$[NOx]_{emiss,k,h} = \sum_l P_{l,k,h} \cdot e_{l,NOx} \tag{15}$$

$$[VOC]_{emiss,k,h} = \sum_l P_{l,k,h} \cdot e_{l,VOC} \tag{16}$$

$$[SOx]_{emiss,k,h} = \sum_l P_{l,k,h} \cdot e_{l,SOx} \tag{17}$$

$$[PM]_{emiss,k,h} = \sum_l P_{l,k,h} \cdot e_{l,PM} \tag{18}$$

$$[CO_2]_{emiss,k,h} = \sum_l P_{l,k,h} \cdot e_{l,CO2} \tag{19}$$

Although CO_2 emissions do not contribute to the atmospheric chemistry, they are accounted in this step to ascertain the possible global warming impacts of DG implementation in the SoCAB.

STEP 8. To fully characterize the emissions coming from potential DG operation in the SoCAB at the level required by the air quality model, a further speciation of the above criteria pollutants, i.e., NOx, CO, VOC, SOx, and PM, must be applied. This step requires that one directly correlate each of the pollutant emissions calculated in the first seven steps to the pollutant flux rates that are required by the particular chemical mechanism that the AQM is using. In this particular case, the species that are considered in the AQM are those associated with the CACM mechanism. Use of the CACM mechanism requires splitting of NOx emissions into NO and NO_2, SOx emissions into SO_2 and SO_3, characterization of the VOCs as 5 distinct hydrocarbon compounds, and supplying a distribution of particulate matter that is comprised of 19 species and 8 size classes. The process of accomplishing this is presented in more detail in section 2.8.

STEP 9. The effects of any emissions displacement that may occur as a result of DG installations in the SoCAB are accounted for in step nine. Once the speciated emissions from the DG realistic scenario are known, the process described in section 2.10 to account for displaced emissions due to the operation of CHP DG units (or other emissions displacement) is applied. The resulting net emissions fluxes are calculated in this step by direct subtraction of emissions fluxes that account for displaced emissions.

STEP 10. The last step that is required to complete the development of a realistic scenario based upon land-use data is to take into account other realistic factors that can affect the final emissions levels for the particular date that one desires to simulate. The factors that can be include first the date of the simulation (upon which all factors above must be scaled) together with an adoption rate curve, or any performance degradation that one wants to include for the installed DG systems.

With regard to the adoption rate, both a realistic exponential increase and a less realistic linear increase of the accumulated DG power installed in the period 2003-2010 have been implemented in the current study as shown in section 2.11 of this report. The performance degradation can include both an increase of criteria pollutant emissions and a decrease of electrical efficiency that will likely occur throughout the lifetime of any DG unit. As practically no public data is available on DG performance degradation are currently available, the APEP team suggests a 10% annual increase in criteria pollutant emissions. According to the estimated adoption rate, 2 average years of installation for the DG units are determined, one for the DG fleet as adopted in the period 2003-2006, and the other for the one introduced in 2007-2010. The corrections of net emissions for both the 2003-2006 and the 2007-2010 DG fleets due to selected annual performance degradation are determined according to their average year of installation. See section 2.11 for more details of this procedure.

3.3 Spatial distribution of DG power, total power per sector and DG technology mix based on land-use data

Applying the procedure described in the previous section has produced a spatial distribution of DG power in the SoCAB for year 2010 that is based on land-use GIS data. Figure 12 presents a contour plot of the DG power (on a log scale) for a DG scenario with a 10% of the increased power in the basin being met by DG. This type of spatial distribution, called a land-use weighted spatial distribution, is typical of the realistic DG scenarios that have been developed in the current program.

Figure 13 presents a comparison of the land-use weighted spatial distribution of DG power and other spatial distributions used in this study; namely, population weighted, population growth weighted, and even spatial distributions. Except for the non-realistic even spatial distribution of DG power, the other 3 distributions show relatively similar patterns with some differences that are worthy of note. Both the population weighted and the population growth weighted spatial distributions have higher DG power peaks, whereas the land-use based distribution spreads DG power to more locations (e.g., south of Riverside) and reduces the amount of power in the peak zones. Note also that the locations of peak power production occur in slightly differing regions of the SoCAB, representing zones permitted for industrial use and residential use for the land-use weighted and population and population growth weighted cases, respectively.

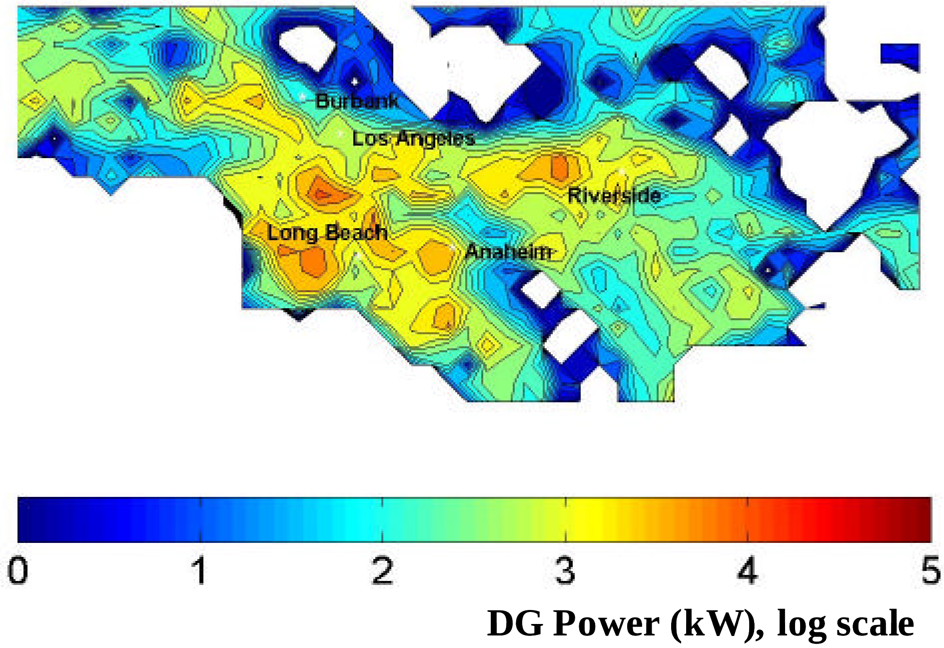


Figure 12: Spatial DG Power Distribution based on land-use data

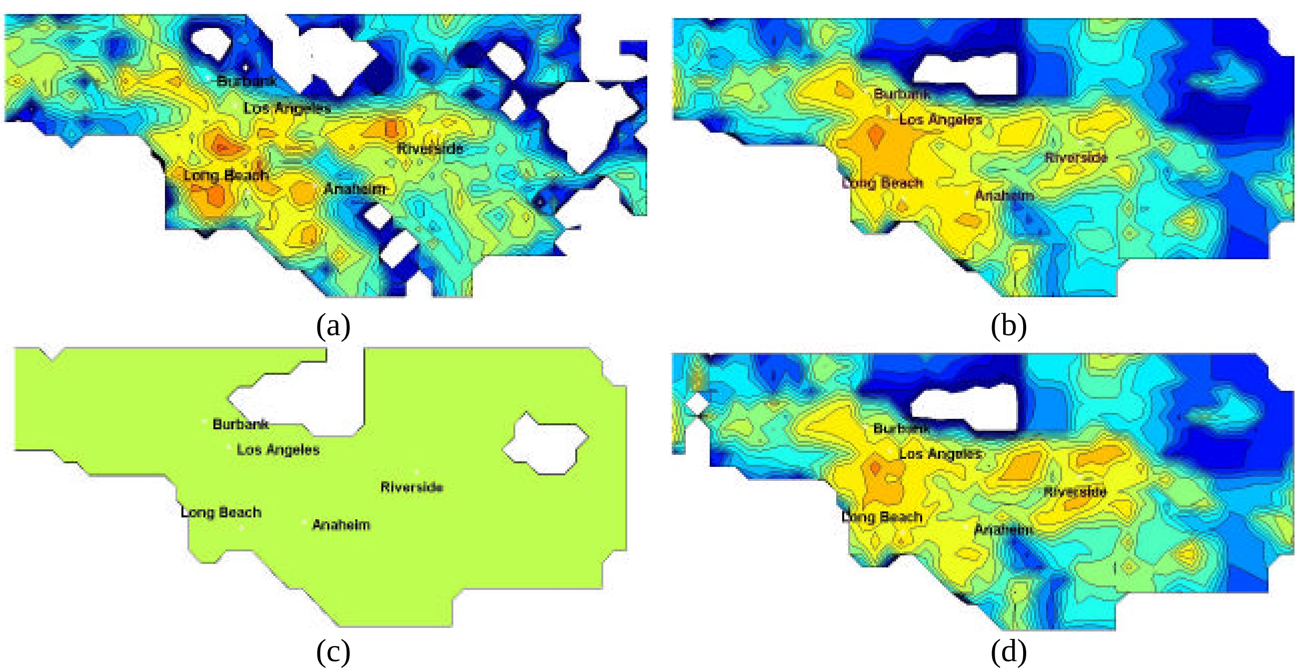


Figure 13: Comparison amongst 4 spatial distributions of DG power in the SoCAB: (a) land-use weighted; (b) population weighted; (c) even; (d) population growth weighted.

The application of the 10-step systematic approach for developing realistic DG implementation scenarios provides a reasonable distribution of DG power among sectors and among DG types in the SoCAB for 2010. Figure 14 presents the total DG power distribution amongst the various sectors considered in the current study. About 60% of total DG power is implemented in the industrial sector and more than 30% is going to the commercial-institutional sector (the sum of categories “commercial” and “other”). Only a small fraction of the DG power that is anticipated for installation in the SoCAB by 2010 is installed to meet power demands in the residential sectors.

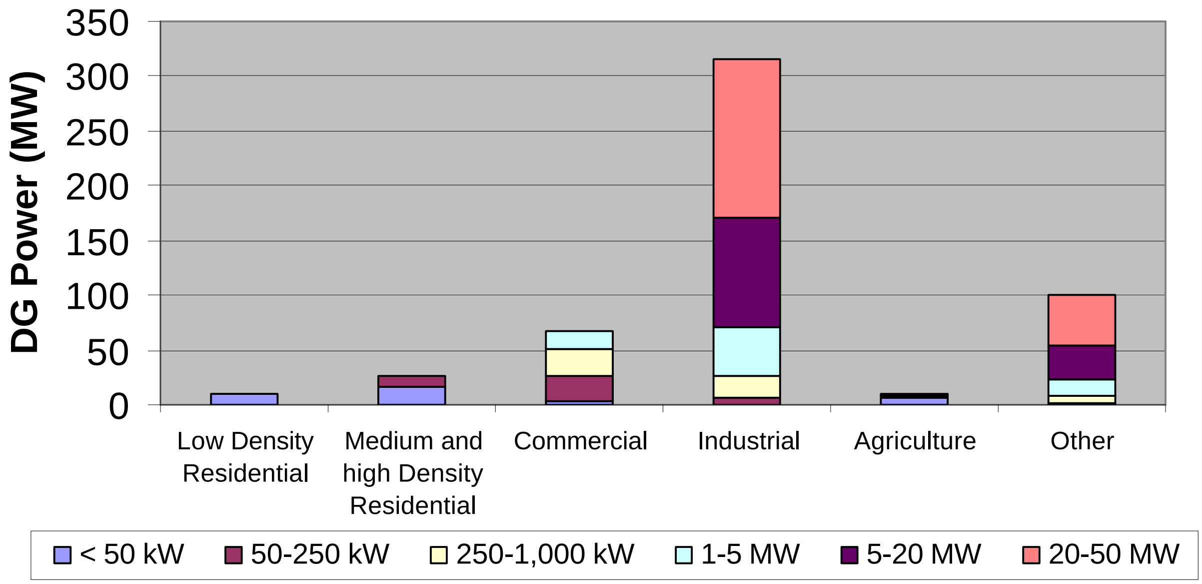


Figure 14: Total DG power distribution among sectors

Figure 15 presents the relative contribution of each type of DG technology considered in the current study for the systematic approach for developing a DG scenario outlined above. According to this approach, almost 50% of the DG market is being met by gas turbines, whereas ICEs, MTGs, PV, and FC account for 17%, 15%, 5%, and 10% of the total 2010 DG power market, respectively. These figures are presented on a total power contribution basis, and as a result do not accurately reflect the number of units installed, but, rather the contribution to total power demands that are met by each type of DG technology. For example, one large industrial gas turbine contributes much more to the power demand (and emissions) than does a host of small fuel cells installed in the residential sector.

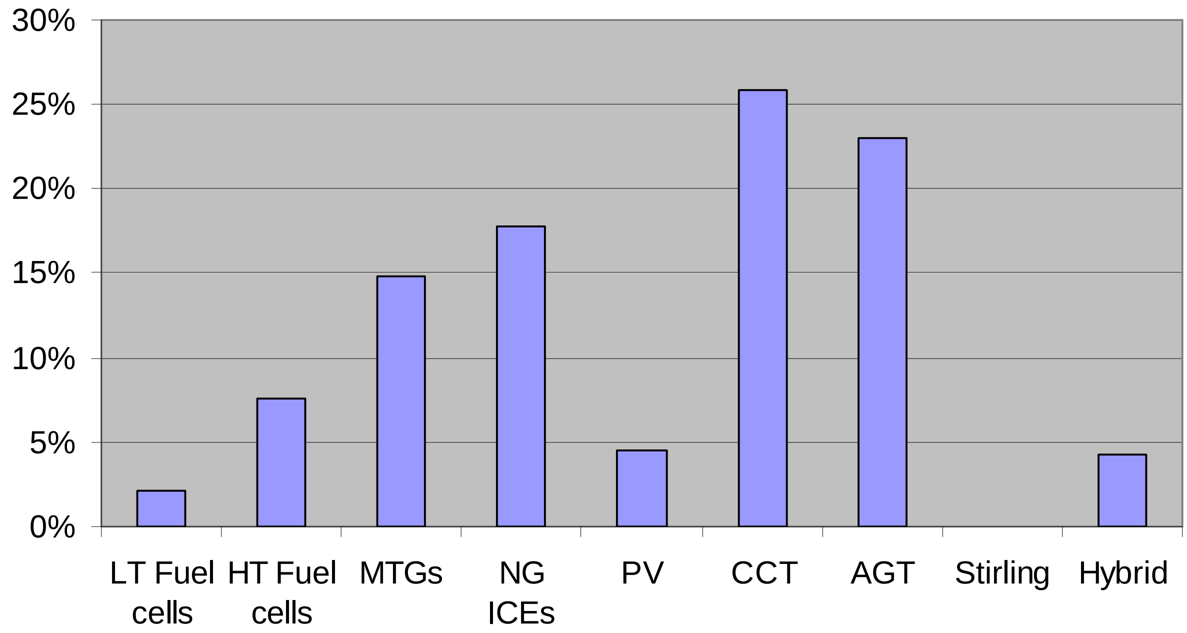


Figure 15: Total power distribution by DG type

4 REFERENCES

Allen, P. (2002). SoCAB emissions inventory, The California Air Resources Board.

Allison, J. E. and Lents, J. (2002). "Encouraging distributed generation of power that improves air quality: can we have our cake and eat it too?" Energy Policy **30**(9): 737-752.

ARB (2000). ARB emission information for facilities, http://www.arb.ca.gov/app/emsinv/facinfo.

Boedecker, E., Cymbalsky, J. and Wade, S. (2000). Modeling Distributed Generation in the NEMS building models, Energy Information Administration.

CEC (1999). Market Assessment of CHP in the State of California, Onsite Sycom Energy Corporation, prepared for California Energy Commission.

CEC (2001). California Power Plants Database, California Energy Commission, http://www.energy.ca.gov/database/index.html#powerplants.

CEC (2003). Current, Expected and Approved Peaker Power Plants, California Energy Commission, http://www.energy.ca.gov/maps/PEAKER_MAP.PDF.

Chin, G., Dixon, H., Kato, J. and Komorniczack, A. (2001). Guidance for the Permitting of Electrical Generation Technologies, Air Resources Board.

CPUC (2003). California Self-Generation Incentive Program. Second Year Impacts Evaluation Report, Tirón Inc., prepared for Southern California Edison.

EIA (1999). 1998 Manufacturing Energy Consumption Survey (MECS), Energy Information Agency.

EIA (1999). A Look at Residential Energy Consumption in 1997, Energy Information Agency.

EIA (2000). A Look at Building Activities in the 1999 Commercial Buildings Energy Consumption Survey (CBECS), Energy Information Agency.

Ianucci, J., Horgan, S., Eyer, J. and Cibulka, L. (2000). Air Pollution Emissions Impacts Associated with the Economic Market Potential of Distributed Generation in California, Distributed Utility Associates, prepared for The California Air Resources Board.

Kay, M. (2003). Personal communication, SCAQMD.

Lenssen, N. (2001). "The California Power Crisis. The Role of Distributed Generation." Cogeneration and On-Site Power Generation **2**(3).

Lents, J. and Allison, J. E. (2000). Can We Have Our Cake and Eat It, Too? Creating Distributed Generation Technology to Improve Air Quality, University of California Riverside, CA, prepared for the Energy Foundation.

Little, A. (2000). Opportunities for Micropower and Fuel Cell Gas Turbine Hybrid Systems in Industrial Applications, Arthur D Little, prepared for Lockheed Martin Energy Research Corporation and the DOE Office of Industrial Technologies.

Marnay, C., Chard, J. S., Hamachi, K. S., Lipman, T., Moezzi, M. M., et al. (2001). Modeling of Customer Adoption of Distributed Energy Resources, Consortium for Electric Reliability Technology Solutions, Ernest Orlando Lawrence Berkeley National Laboratory, prepared for California Energy Commission.

Nexus (2002). Performance and Cost Trajectories of Clean Distributed Generation Technologies, Energy Nexus Group, prepared for the Energy Foundation.

NREL (2003). Gas Fired Distributed Generation Technology Characterization: Microturbines, Energy and Environmental Analysis, Inc, prepared for National Renewable Energy Laboratory.

RAP (2001). DG Emissions, National Renewable Energy Laboratory, on-going study for Regulatory Assistance Project, http://www.rapmaine.org/workgroup.html.

SCAQMD (2000). Best Available Control Technology Guidelines, SCAQMD.

SCAQMD (2003). Addendum to the proposed modification to the draft 2003 air quality management plan and additional comments and responses, South Coast Air Quality Management District

Tomashefsky, S. and Marks, M. (2002). Distributed Generation Strategic Plan, California Energy Commission.

5 APPENDIX A: RESULTS FROM THE FIRST INDUSTRY STAKEHOLDER WORKSHOP (19 SEPTEMBER, 2002)

5.1 Stakeholder Workshop Description

A workshop was organized and hosted by the Advanced Power and Energy Program at UCI to garner help from industrial stakeholders to develop accurate DG implementation scenarios and to adequately consider technologies of interest to the stakeholders. The workshop was characterized as:

Workshop Title:	***"Distributed Generation Implementation Scenarios for Air Quality Impacts in the South Coast Air Basin"***
Workshop Date/Time:	Thursday, September 19, 9:00am to 4:30pm
Workshop Location:	Advanced Power and Energy Program, University of California, Irvine

The purpose of this workshop was to: (1) provide the stakeholders a brief overview of the current air quality impacts of DG project, (2) receive important feedback and guidance from the DG community, (3) accept critique and modify program direction and approach appropriately, and (4) better ground the research effort to garner insight into real potential air quality impacts of DG.

The discussion topics of this workshop included:

(1) Program overview and approach
(2) Types of DG considered
(3) Characteristics of DG considered
(4) DG Scenarios Development
(5) DG Scenario Screening
(6) Examples of Air Quality Impacts

The agenda for the workshop was (discussion/presentation leader in parentheses):

9:00am	Introductions/Agenda Review (Prof. Scott Samuelsen)
9:15am	Program Overview and Approach (Dr. Jack Brouwer)
9:45am	Discussion of DG Types and Characteristics
10:15am	Break
10:30am	Distributed Generation Scenarios Development and Screening (Dr. Marc Medrano, Dr. Jack Brouwer)
11:00am	Discussion of Scenario Development and Screening
11:30am	Air Quality Modeling Approach and Sample Results (Prof. Donald Dabdub, Mr. Marc Carreras)
12:00pm	Lunch (Establish Breakout Groups)
1:00pm	Breakout Sessions (Prof. Scott Samuelsen – red; Dr. Jack Brouwer – green; Dr. Marc Medrano – yellow) Types of DG considered (20 minutes) Characteristics of DG considered (20 minutes)

Scenario Development Strategy (20 minutes)
Scenarios themselves (20 minutes)
Scenario Screening (20 minutes)
Air Quality Issues (20 minutes)
3:00pm Break
3:30pm Summary of Breakout Sessions (Reports from red, green, & yellow breakout groups)
4:15pm Summary Discussion
4:30pm Adjourn

Attendees of the Stakeholder workshop are presented in Table 24.

Table 24. List of attendees and corresponding organizations for the DG industry stakeholder workshop held at UCI on 19 September, 2002.

NAME:	ORGANIZATION:
Marty Kay	SCAQMD
Cynthia Verdugo-Peralta	SCAQMD
Matthew Olson	Alliance Power
Brian Moreau	Alliance Power
S. Zwicker	Bowman Power Systems
Grant Chin	CARB
Linda Kelly	CEC
Marla Mueller	CEC
Brian Fox	Capstone Turbines
Bill Treece	Capstone Turbines
Mike	Coalition for Clean Air
Kevin	Coalition for Clean Air
G. Dettmer	Elliot Turbines
Babu Nott	EPRI
Gordon Hester	EPRI
Stephen Torres	FuelCell Energy
Robert Castro	LADWP
Benjamin Beaver	Millenium Cell
C. Z. T.	Pacific Gas & Electric
M. Banks	Planergy
J. Edwards	U.C. Berkeley
Todd O'Conner	O'Conner Consultants
Dana Freund	Southern California Gas
Ed Becker	Southern California Gas
M. Nazemi	SCAQMD
M. Mills	SCAQMD
Stephanie Hamilton	Southern California Edison
Tom Dossey	Southern California Edison
	Clean Air Now
Jack Brouwer	UCI
Scott Samuelsen	UCI
Marc Medrano	UCI
Donald Dabdub	UCI
Marc Carerras	UCI
Marcos Rodriguez	UCI

5.2 APEP Compilation and Assessment of Stakeholder Recommendations

The Advanced Power and Energy Program (APEP) of UCI recorded the input from stakeholders at this workshop and compiled the notes that were gathered as a result of the questions raised during the formal presentations, issues discussed and recommendations made during the full discussion periods and in each of the three breakout sessions, held in the afternoon. From all of this input from Stakeholders, APEP researchers compiled and assessed the stakeholder recommendations as follows in this section.

5.2.1 Recommendations to Definitely Include

- For DG spatial distribution:
    - Base distribution on population and population growth. (Population - reflects installed base--power, and peak power demand, whereas Population Growth reflects emerging opportunities.)
    - Consider zoning/permitting in scenario development.
    - Use economic “models” that are realistic for market penetration (e.g., CHP) – limited per discussion below.
    - Use utility interconnect data and other applicable statistics – if data are available/provided (need cooperation of LADWP, SCE).
    - Use highway miles scenario for model “sensitivity” only

- For DG temporal distribution:
    - Account for the likelihood that the majority of DG will NOT be base-loaded

- For DG technology mix:
    - Remove windmills from consideration in the South Coast Air Basin (SoCAB).
    - Natural gas-fired ICEs should be included in the scenarios (check PM emissions rate).
    - For 2010 DG Scenarios, incorporate a population of DG that reflects emissions performance at the date of installation. (Include likely performance degradation)
    - Account for significant adoption of CHP systems (between 40 and 60% - FuelCell Energy, 65% - Capstone) in this timeframe.

- For DG penetration:
    - 20% of increase is most likely “worst case” penetration scenario (not a consensus opinion with many supporting 20%).

- For DG Scenarios in general:
    - Adopt the following DG classifications:
        - Residential: 1kW to 5kW (FC, PV)
        - Commercial/Small Industrial: 25kW to 500kW (PV, MTG, FC)
        - Large Commercial/Institutional: 500kW to 2MW (reciprocating engines)

  - Large Institutional: 2MW to 50MW (GT)
- Account for CHP emission offsets (e.g., boiler replacement).
- Develop baseline scenarios for both the "uncontrolled" and "controlled" 2010 base case emissions inventory (use the latest "release" relative to the project schedule).
- Strongly differentiate cases that are "forecasts" (i.e., likely or realistic) from those that are "excursions" (i.e., used for engineering insight or brainstorming).
- Do a few excursions to bracket the problem and capture uncertainty ("you never know").

- For DG Emissions Characterization:
  - For larger systems (>5MW?) emissions offsets must be purchased and should be included in the scenario.
  - Use the CARB, or AQMD standards that apply to the technology, size, and application.
  - Report emissions of CO_2 as a result, but don't use possible CO_2 impacts or regulatory action in development of scenarios (perform a separate DG scenario calculation that accounts for non-regional sources as well).
  - Carefully include an analysis of displaced emissions (especially for CHP, opportunity fuels, etc.).
  - Apply the 2003 and 2007 ARB standards scenarios to the moderate penetration case.

5.2.2 Recommendations to Consider

- For DG Spatial Distribution:
  - Focus on consumption growth to locate power generators.
  - Use current transmission grid constrained locations as a weighting consideration.

- For DG Technology Mix:
  - Solar is not expected to contribute a high percentage of DG, rather, consider solar-thermal combined with heat and power (e.g., Nevada and North Carolina).
  - PV is only residential (But, penetration could be increased in commercial applications due to future policy decisions (e.g., AB970 incentives, San Francisco Bond)
  - Add solar-thermal and external combustion engines (e.g., Stirling external combustion engine).
  - Focus on natural gas DG.
  - Categorize and organize as existing technologies and emerging technologies.
  - Consider digester gas installations in the Chino Valley.

- Consider the use of DG at oil and gas recovery locations.
- Assume that large plants (3-50 MW) are more likely to use gas turbine. 1-3 MW gas turbines and ICE. Below 1 MW plants are more likely to incorporate small DG technology (MTGs, FCs).
- Diesel fuel related technology will not be used in the basin in the future.
- Hydrogen ICEs should be considered as another potential source – with H_2 generated "in the basin."
- Consider larger combined cycle plants – could affect DG adoption in vicinity.
- Gas turbine fuel cell hybrid systems will not be widely available by 2010.
- Consider fuel cells vehicles – only as linked to hydrogen production and refueling.

- For DG temporal distribution:
  - Characterize DG based on operational hours, and applications in various market segments (particularly important considering temporal aspects of the simulation)
  - Since majority of DG will NOT be base-loaded (60% not base-loaded), need to define by application and consider TOU pricing.

- For DG Emissions Characterization:
  - "Worst Case" must include diesel-fueled internal combustion engines (ICE).

- For DG Scenarios in general:
  - Consider applications and market segments when determining both penetration and DG characterization (e.g., chiller, hot water, steam, residential, industrial, commercial).
  - Include economic (value driven) and policy factors in scenario development including (1) current economic incentives, (2) renewable portfolio standard, (3) departing load charges, (4) CHP benefits, (5) fuel availability, (6) cost of fuel, (7) applicable CC & R's, (8) zoning / permitting, (9) applicable tariff, in the DG scenario development. (NOTE: this is quite challenging, and could comprise a completely new DG penetration study project – we suggest a limited economic analysis)
  - Up to 15% of the existing load on a substation does not require an upgrade. Above that, there are additional costs, which should be considered as an economic constraint for DG deployment.
  - Limit the cases to a top 10 list, and add sub-cases.
  - Use hydrogen more widely in a brainstorming scenario including hydrogen infrastructure development. While low penetration may be true for 2010, H_2 may be prominent in 2050.

- Include consideration of UPS, premium power increased demands for DG.
- Consider a “worst case” scenario that allows diesel gen-sets to operate more than 200 hours.
- Divide DG into “clean but polluting” and “non-polluting” categories
- Correlate results to DG size, type, application:
  - Residential: 1kW to 5kW (FC, PV)
  - Commercial/Small Industrial: 25kW to 500kW (PV, MTG, FC)
  - Large Commercial/Institutional: 500kW to 2MW (reciprocating engines)
  - Large Institutional: 2MW to 50MW (GT)

5.2.3 Recommendations to Reject

- Consider multimedia environmental impacts (e.g., noise, EMF, water, soil, etc…)
- Consider retiring plants, possible large demand due to lack of merchant plant installations as an opportunity (if not replaced) or discouragement for DG (if replaced).
- Consider fuel cell vehicle emissions in the scenarios.
- Be careful to not analyze two (or more) DGs with same emissions profiles (and end uses).
- Do an emergency generator operating case. (potential overlap with UCR study)
- Consider diesel-fueled DG can operate continuously in basin.
- Consider doing only emission modeling instead of air quality modeling.

5.2.4 APEP Actions

- Differentiate between regional and local impacts. Local impacts need to be studied closer. Identify where impacts are expected to be stronger.
- Demonstrate early on that DG does have an impact (e.g., model sensitivity to incremental emissions associated with DG)
- Determine if NG reciprocating engines are the same, better than, or worse than MTG.
- Define bounds on the problem. DG might not have an impact even in the worst case.
- Have another meeting to report back to this group of stakeholders.
- Revise natural gas ICE emission factors. They appear to be too high for PM especially.
- VOC emissions for a PEMFC seem too high.
- Need to know how the AQMD, ARB or EPRI (E2I) will use results, to narrow the span.

- Do 2007 ARB standards include CHP credit?
- How does definition of DG differ from ARB definition? (SB1298)
- Gain access to the “controlled” emission inventory for 2010
  - Get unprocessed emissions inventory
  - Get controlled emissions inventory
- Discuss the better way to approach CHP for the emissions accounting
- Compile more emissions rates from other sources and also partial performance emissions factors.
- Find out which land parcel classification (zoning) information for SoCAB is available in GIS or other formats.
- Try to get information on hourly electricity profiles for industrial, commercial and residential sub-segments from SoCAB utilities.

6 APPENDIX B: RESULTS FROM THE SECOND INDUSTRY STAKEHOLDER'S WORKSHOP (21 MAY, 2003)

6.1 Stakeholder Workshop Description

A workshop was organized and hosted by the Advanced Power and Energy Program at UCI to garner help from industrial stakeholders to develop accurate DG implementation scenarios and to adequately consider technologies of interest to the stakeholders. The workshop was characterized as:

Workshop Title: ***"Distributed Generation Implementation Scenarios for Air Quality Impacts in the South Coast Air Basin – Part II"***
Workshop Date/Time: Wednesday, May 21, 2003, 9:00am to 4:30pm
Workshop Location: Advanced Power and Energy Program, University of California, Irvine

The purpose of this workshop was to: (1) provide you with an update on this air quality impacts of DG project, (2) receive final feedback and guidance from the DG community on the DG implementation scenarios, and (3) accept critique from the community and modify program direction, approach, and DG implementation scenarios appropriately.

The discussion topics of this workshop included:

(1) Update on DG implementation scenario development approach,
(2) Description of DG implementation scenarios developed to-date,
(3) Examples of Air Quality Impacts,
(4) Feedback and Critique on scenario development approach, and
(5) Feedback and Critique of actual scenarios developed.

The agenda for the workshop was (discussion/presentation leader in parentheses):

9:00am Introductions/Agenda Review (Prof. Scott Samuelsen)
9:15am Program Overview and Update (Dr. Jack Brouwer)
9:30am DG Implementation Scenarios Development Approach (Dr. Marc Medrano, Dr. Jack Brouwer)
9:45am Discussion of DG Implementation Scenarios Development Approach
10:15am Break
10:30am DG Scenarios Developed to-date (Dr. Marc Medrano, Dr. Jack Brouwer)
11:30am Discussion of DG Implementation scenarios developed to-date
12:00pm Lunch
1:00pm Sample Air Quality Modeling Results (Prof. Donald Dabdub, Mr. Marc Carreras)
1:45pm Discussion of Air Quality modeling results
2:00pm Breakout Sessions (Prof. Scott Samuelsen – red; Dr. Jack Brouwer – green; Dr. Marc Medrano – yellow)
Scenario Development Strategy (30 minutes)
Scenarios themselves (30 minutes)

	Air Quality Issues (30 minutes)
3:30pm	Break
3:45pm	Summary of Breakout Sessions
	Reports from red, green, and yellow breakout sessions (15 minutes each)
4:30pm	Adjourn

Attendees of the second Stakeholder workshop are presented in Table 25.

Table 25. List of attendees and corresponding organizations for the DG industry stakeholder workshop held at UCI on 21 May, 2003.

Attendee Name	Organization
Stuart Cooley	City of Santa Monica
Martin Kay	SCAQMD
Edan Prabhu	Flex Energy
C.C. Lee	US EPA
Gerome Torribio	Southern California Edison
Stephanie Hamilton	Southern California Edison
James Westbrook	Blue Scape Environmental
Thai Ta	LADWP
Tod O'Connor	STM / GTI
Grant Chin	ARB
Marla Mueller	CEC
Chris Tufon	PG & E
Stephen Torres	FuelCell Energy
Dave Pitts	Caterpillar, Inc
Keith Davidson	DE Solutions
Donald Dabdub	UCI
Marco Rodriguez	UCI
Kevin Duggan	Capstone Turbine Corp
Mike Mills	SCAQMD
Gordon Hester	EPRI
Kourosh Mehrayin	PROBE
Martin Schlageter	Coaliiton for Clean Air
Mohsen Nazemi	SCAQMD
Vince McDonell	APEP
Jack Brouwer	APEP
Marc Medrano	APEP
Marc Carreras	UCI
Karl Sheldon	GE Global Resreach Center
Henry Mak	Sempra Utilities
Eric Wong	Combined Energy Systems
Denise Diaab Canning	T&D Planning, Communication, and CPUC Regulation
J. Edwards	UC Berkeley
Wesley Sullens	Xenergy
Brian Moreau	Alliance Power
John Scheibel	EPRI
Minh Nguyen	GE Power Systems

6.2 Recommendations to Definitely Include

- Obtain SCE data, LADWP data, and SCPPA data on current installed DG and trends to both benchmark and check our estimates for DG adoption rates and technology mix.
- Construct a Business as Usual scenario based on the above data
- Make sure ammonia emission factors are consistent with AQMD's regulations
- Check CEC "requirement" for percentage of renewable energy in mix of electricity production and include this level in the scenarios
- Divide the DG into those that are permitted (under SCAQMD rules) and those that are certified (under ARB rules)
- For permitted sources, consider the type of engine technology (different emissions profiles):
  - Lean burn: for large projects, can afford SCR, usually gas turbines, higher efficiency (~39%)
  - Rich burn: smaller projects, three way catalyst, lower efficiency (~34%) (Note: AQMD standard same for both, kg/kw-hr; few lean projects)
- Look to the source test data of AQMD for emissions levels
- Spanning scenarios should include a mix of technologies (vs. heavily MTG weighted)
- The "realistic" technology mix should definitely include more internal combustion engines (ICE) and gas turbines (GT) and less fuel cells (FC) and hybrids in technology mix
- Consider that use of averages in the generation of power per cell may reflect an unrealistic specification of DG. As a result, specific cells may need to accommodate instances of specific DG sizes.
- Consider a spanning scenario that is almost 100% ICE and MTG

6.3 Recommendations to Consider

- Should consider increased adoption of opportunity fueled DG
- Should consider more displaced emissions – we include for CHP, opportunity fuels, port, but not for any displaced electricity currently – we will consider a spanning case that includes electricity displacement – significant caveat: studies to-date have not shown an actual proven in-basin displacement
- Add start-up emissions for peak power spanning scenarios. This in challenging since we do not have a data source, but, we will consider a spanning case where these are estimated.
- Recognize that some gas turbine NOx control may be SCONOX (non-ammonia) versus SCR (potential ammonia slip) and will not contribute to the ammonia slip emissions
- Penetration may be too low – check current permitting records from AQMD (use SCE, LADWP, Muni interconnect data to check)
- Think about the DG duty cycle – most current DG projects are operating base loaded and using the grid for peaking (this is especially the case when not exporting power, when using CHP)
- Consider utility rates, demand charges, etc. in analyses of duty cycle

- The 2007 standards may drive more FC adoption, but, ICEs and GTs will still dominate (in terms of MW capacity) without any violation of standards (most of these will be permitted by SCAQMD vs. certified by ARB)
- Consider demand reduction, energy efficiency and energy saving methods that can be coupled with DG - introduce these into the scenarios to see what impact taking credit for energy savings methodologies may have – spanning scenario or uncertainty analysis
- Think about a hydrogen economy scenario
- Think about a high spark-spread scenario
- Consider the additional benefit of installed DG that lowers the peak demand. Is there a large emissions benefit associated with easing the load during peak time in existing plants (e.g., peaking plants in the basin)?
- In the spanning scenarios, develop a database that could provide a capability to estimate the impacts of a specific set of DG installation conditions
- Land use, and sector spatial distributions are more appropriate than population growth

6.4 Recommendations to Reject

- Develop an overall statistical index for air quality
- Suggest expanding the project to consider other sources beyond DG. AQMD is about to put a plan for 2003, using similar tools to forecast air quality concentrations.

6.5 APEP Actions

1. Work on effective presentation formats for both reports and presentations.
2. Obtain SCE data, LADWP data on DG installations and check our numbers versus the observed current trends
3. Contact Southern California Public Power Authority (SCPPA) to obtain data on DG
4. Make sure ammonia emission factors are consistent with AQMDs regulations
5. Check CEC “requirement” for percentage of renewable energy in mix of electricity production
6. Divide the DG into those that are permitted (under SCAQMD rules) versus those that are certified (under ARB rules)
    a. Obtain and use current BACT standards for appropriate permitted equipment
    b. Use ARB certified emissions rates for 2003, 2007 or measured emissions (if lower than ARB standards) for the certified equipment.
7. Use technology mixes in the spanning scenarios
8. Consider a “spanning” case that includes more displaced emissions
9. Include more ICE, GT and less FC and hybrid in the technology mix
10. Add start-up emissions for peak power spanning scenario.
11. Think about actual size of DG units and how this affects the spatial distribution (distinct sizes should be included for some, especially larger, DG)

6.6 Raw Workshop and Discussion Notes

6.6.1 Previous Workshop Review

- Edan Prabhu: Opportunity Fuels: Are they included.

6.6.2 Scenarios

- Tod O'Conner: SCAPA: Pasadena, Glendale, DWP
- Keith Davidson: Did you consider "displacement of emissions" from existing sources as a result of DG; Jack: NO! Should look at this on at least a sensitivity basis
- Tod O'Conner. Renewable Portfolio policy allows utilities are required to make 20% of new power to come from renewables by 2017 with 1 % per year. Jack: we have spanning cases that will capture.
- SCE: Spanning, should consider concentrated emissions in east part of basin? Jack; have done uniform, and population growth based – effectively concentrates emissions
- Keith Davidson: Is characterization information available? Jack: yes. Will present subsequently. Nexus (Keith), NREL, APEP data, and others all used in the compilations.
- Tod O'Conner: Scenario 16. Will you consider MTG-CHP to DG-CHP? Jack: yes
- Edan Prabhu: Wants basis that most opportunity fuels are spoken for. Between now and 2010 could be opportunity fuels, and throwing them out may miss a huge opportunity. Jack: We most definitely do no throw out. Most likely early adopters. Edan: Use of opportunity fuels could have a significant improvement on air quality. Jack: most true. That is way we consider offsets. Chino is one example that will benefit (although not on our list).

6.6.3 Scenarios Presentation

- What about emissions of CO – they are included, but not presented here.
- What about O_3 (produced in the basin as a result of NOx, VOC emissions and leads to additional PM (secondary organic aerosols).
- Land-Use Data Extraction:
  - Do you have the definitions of low density versus medium to high density residential, yes.
- Approach for Realistic Scenarios:
  - How many i,j,k are you considering (i = 1 to 6 sectors, j = 1 to 5 size classes, k = 1 to 994 cells)
  - How are the $e_{l,k}$ defined (use of literature sources, APEP data, and degradation rate, date of installation, etc.) – we need to do some more work here, especially w.r.t. degradation, date of installation.
- Edison provides interconnect data to CPUC – very useful for benchmarking data, this is reported on a sector basis – data is available for sector type, size type, building type, etc. (Stephanie Hamilton)
- Rich-burn, lean-burn division may be required for the ICEs (Mills, AQMD)
- Looks like ICE technology estimate may be low (Stephanie Hamilton)
- Can we use APEP results to determine the optimal scenario for DG installations – perhaps not "optimal," but certainly identify trends that will improve or reduce air quality.
- Current estimates are low for ICE technology penetration, too high for MTGs

- Where do estimates come from (the market studies presented earlier)
- Given the widely accepted belief that high temperature fuel cells are more applicable to stationary power the estimates for HT fuel cells seem too low compared to LT fuel cells. (Steve Torres)
- Very impressed, very intelligent, thoughtful and well laid out process (Edan Prabhu)
- Are the emissions profiles related to the DG types available? – Yes.
- Need to determine where to install actual units of particular size (cannot just use average data) – Keith Davidson
- Should have a much larger fraction of DG power represented by larger gas turbine and ICEs (since a couple of larger units will have much more significant impacts) – Mosen Nazemi
- Are units that do not meet 2003 or 2007 standards going to be allowed to be installed (ARB standards, or SCAQMD permit is required)
    - Are we comparing apples to apples?
    - BACT applies for larger units – jurisdiction of AQMD
    - Non-permit size – ARB regulations apply
    - District has jurisdiction over permitted units and ICEs need only BACT or LAER
- Since current law requires 2003 and 2007 for DG, why consider anything else? (Steve Torres)
- Matter of jurisdiction – permitted sources fall under BACT (AQMD jurisdiction), non-permitted under ARB (Certification)
- Maybe we should divide technologies as those that are permited versus those that fall under ARB certification law – have a separate estimate for growth/adoption rate of permitted versus certified sources – although moving together, definitely NOT the same (VERY IMPORTANT suggestion – Mosen Nazemi – many in audience agree with this approach)
- Hybrid numbers seem way too high for next ten years, ICEs are under represented. (Keith Davidson)
- Try to use census data for 2001 – just released this week.
- DG mix is controversial – seems inconsistent with intuition – but it resulted from studies – we need your feedback to justify a better mix of technologies – base this on your experience and available trends today.
- Edan Prabhu mentioned having some interconnect data, working with SCE on a project with Mark Rawson, Joe Simpson,
-

7 APPENDIX C: PLOTS OF DG EMISSIONS FACTORS FROM DIFFERENT SOURCES

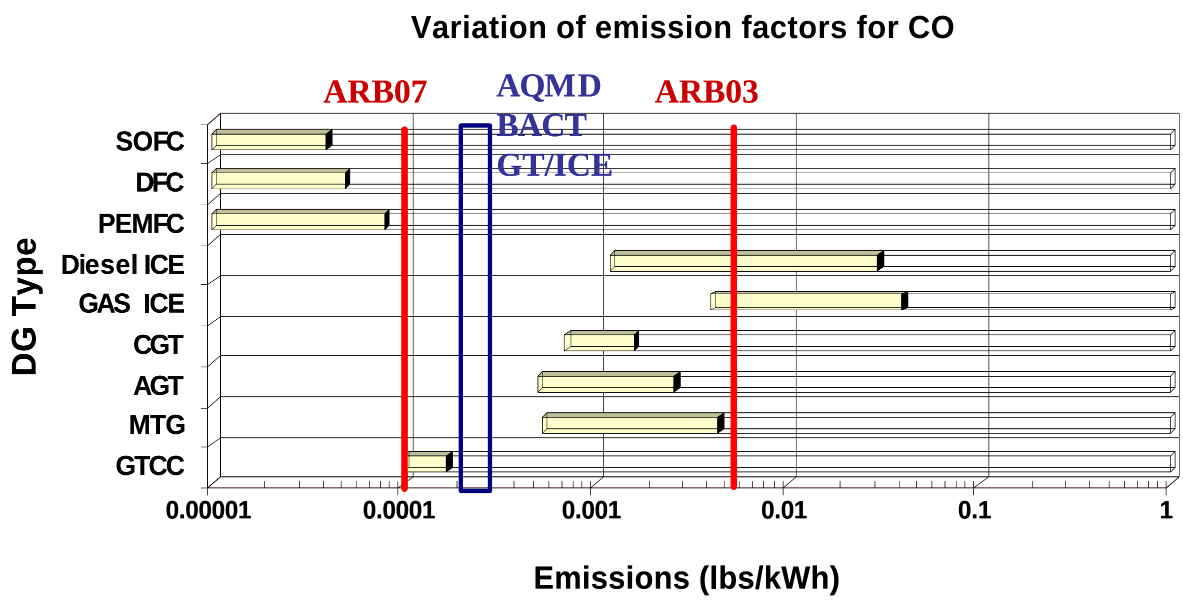


Figure 16: CO emissions factors and ARB and AQMD CO emissions standards.

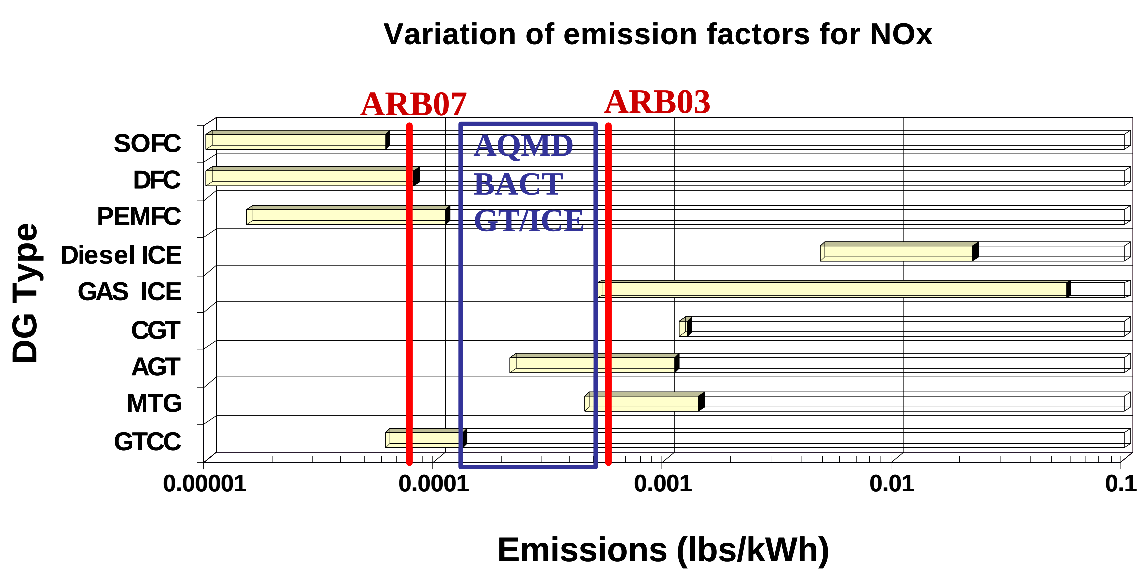


Figure 17: NO_x emissions factors and ARB and AQMD NO_x emissions standards.

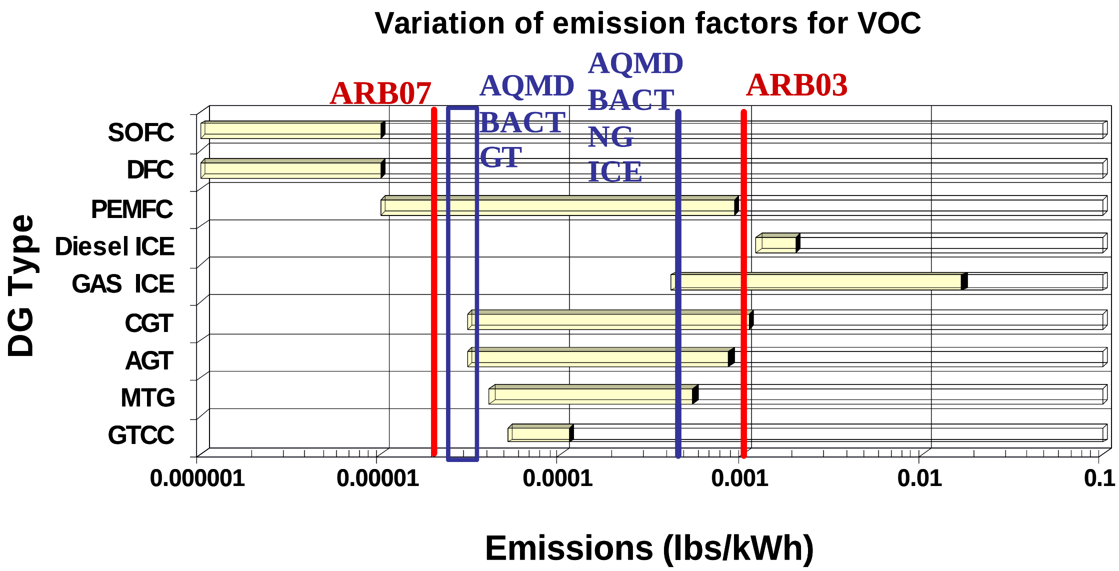


Figure 18: VOC emissions factors and ARB and AQMD VOC emissions standards.

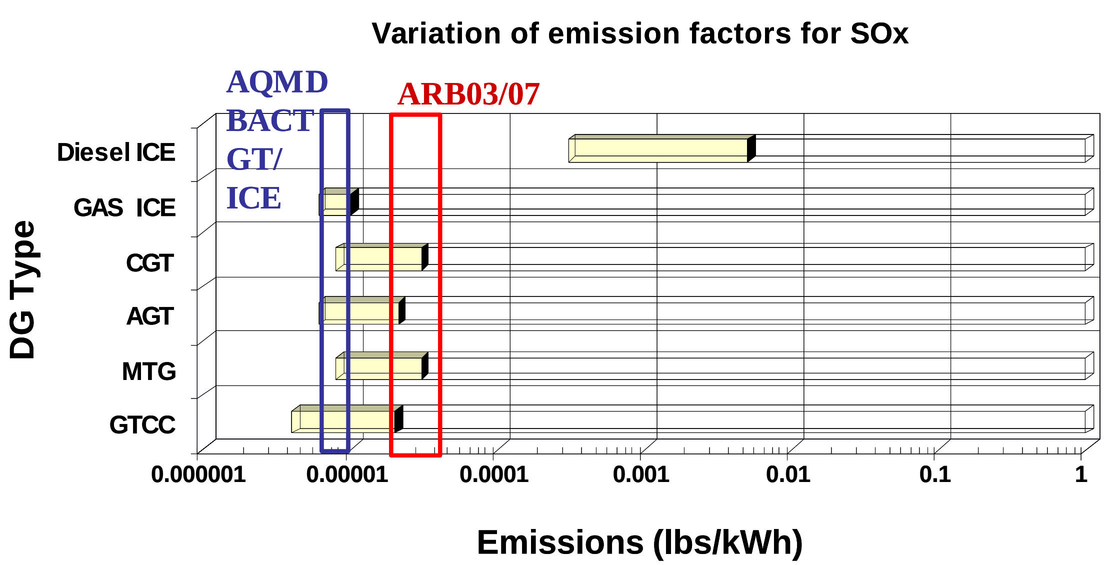


Figure 19: SO_x emissions factors and ARB and AQMD SO_x emission standards.

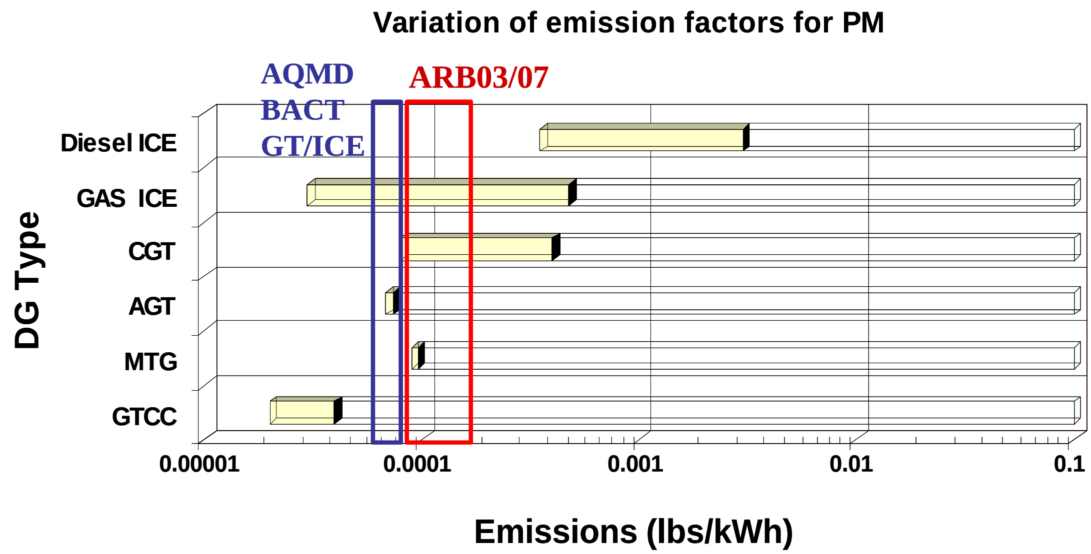


Figure 20: PM emissions factors and ARB and AQMD PM emissions standards.

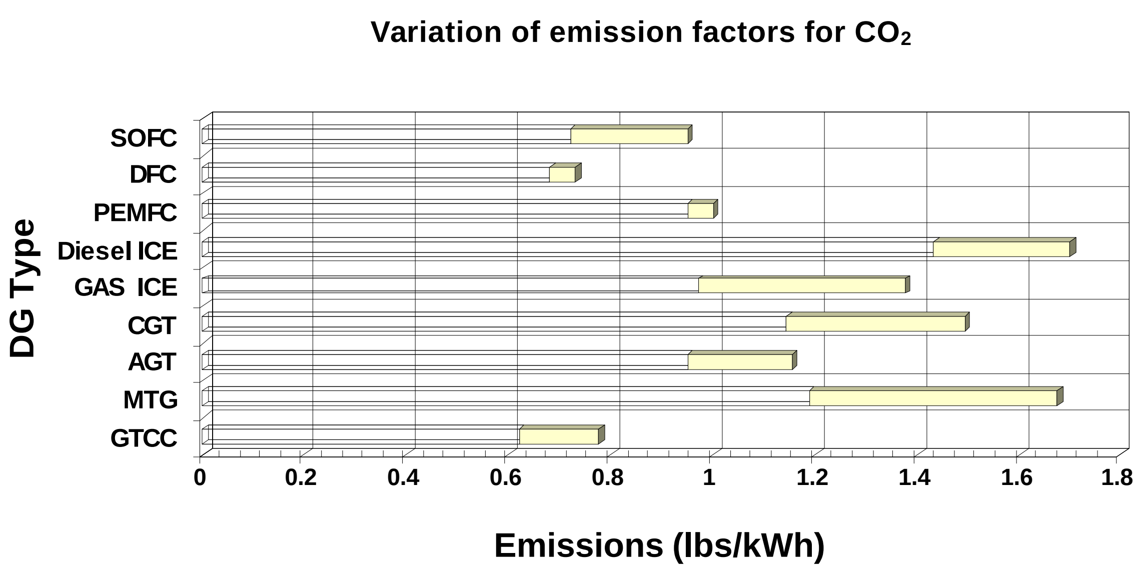


Figure 21: CO_2 emissions factors.

8 APPENDIX D: CONVERSION TOOLS

8.1 Coordinates Web converter

In the first months after the kick off of the current effort we found useful to develop an interactive map of the SoCAB region that could easily and visually translate the pixel coordinates of the map picture into geographical projections coordinates in the Universal Traverse Mercator system, Zone 11 (UTM), as well as the model internal coordinates.
The relationship the X and Y grid coordinates in the air quality model and the UTM Zone 11 system can be written as:

X model coordinates (range 1-80 units) to X UTM coordinates (range: 215-610 km):

$$X_{UTM} = X_M \cdot 5 + 210$$

Y model coordinates (range 1-30 units) to Y UTM coordinates (range: 3685-3830 km):

$$Y_{UTM} = T_M \cdot 5 + 3680$$

The above mentioned conversion tool was successfully developed and posted in Internet for public access in the following URL:

http://albeniz.eng.uci.edu/map/

As an illustrative example, Figure B.1 below shows the UTM and model coordinates when the city of Victorville is clicked.

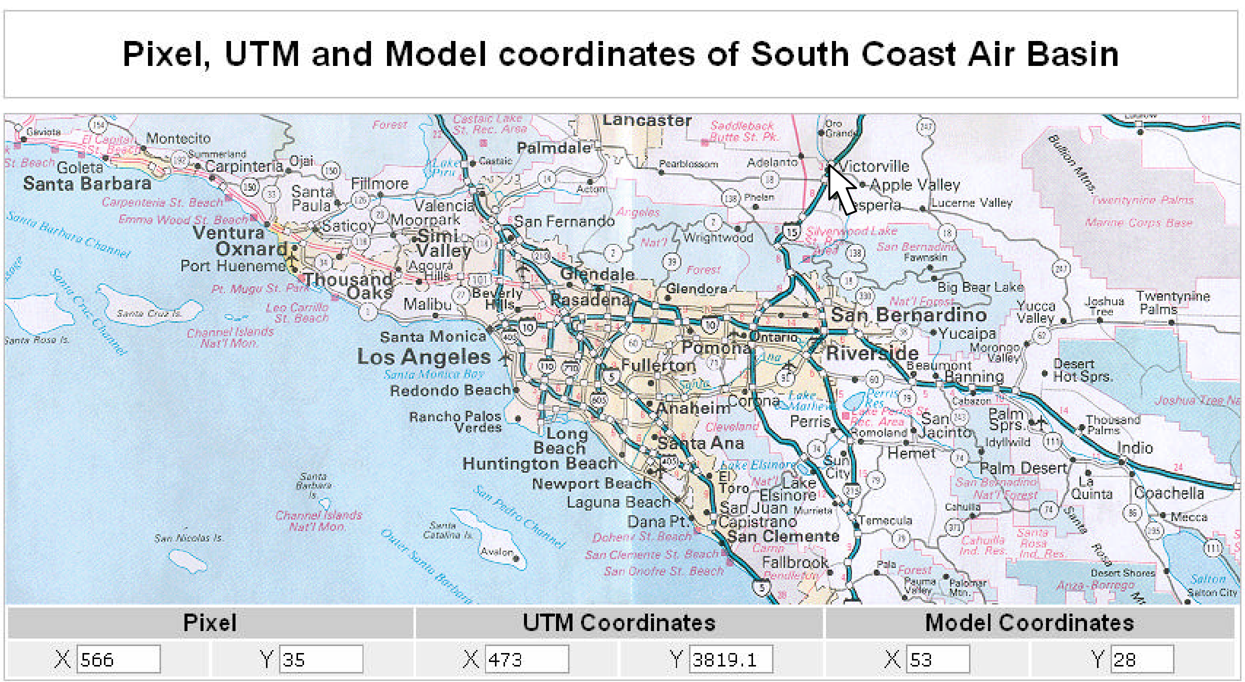


Figure 22: UTM-Model coordinates web converter

8.2 Emission rates converter

We noticed at the early stages of the project that the emission flux units understood by the air quality model (parts per millions x meter / min) were completely different to the typical emission rates units found for distributed generator systems (pounds or kg / hour or pounds or kg/ kWh).
An emission rates converter was successfully developed in Excel to easily relate the two different emission units. The conversion factors used to ascertain how many (ppmv-m/min) of generic pollutant A correspond to x pounds of A/kWh of electricity generated are presented as follows:

$$x\frac{\mathrm{lb\ A}}{\mathrm{kW\cdot h}}\times \mathrm{y}\,\frac{\mathrm{GW}}{\mathrm{cell}}\times\frac{10^6\ \mathrm{kW}}{1\,\mathrm{GW}}\times\frac{1\,\mathrm{h}}{60\ \mathrm{min}}\times\frac{1\,\mathrm{kg\ A}}{2.205\,\mathrm{lb\ A}}\times\frac{1\,\mathrm{mol\ A}}{\mathrm{MW\ A\ kg}}\times\frac{1\,\mathrm{cell}}{25\cdot 10^6\ \mathrm{m}^2}\times\frac{8.314\,\frac{\mathrm{Pa\cdot m^3}}{\mathrm{mol\ air\cdot K}}\cdot 288\,\mathrm{K}}{1.01325\cdot 10^5\ \mathrm{Pa}}\times\frac{10^6\ \mathrm{ppmv\ A}}{\mathrm{mol\ A/mol\ air}}$$

9 APPENDIX E: LOCATION OF LAND-USE PARCELS FOR THE 13 GENERIC LAND-USE CATEGORIES

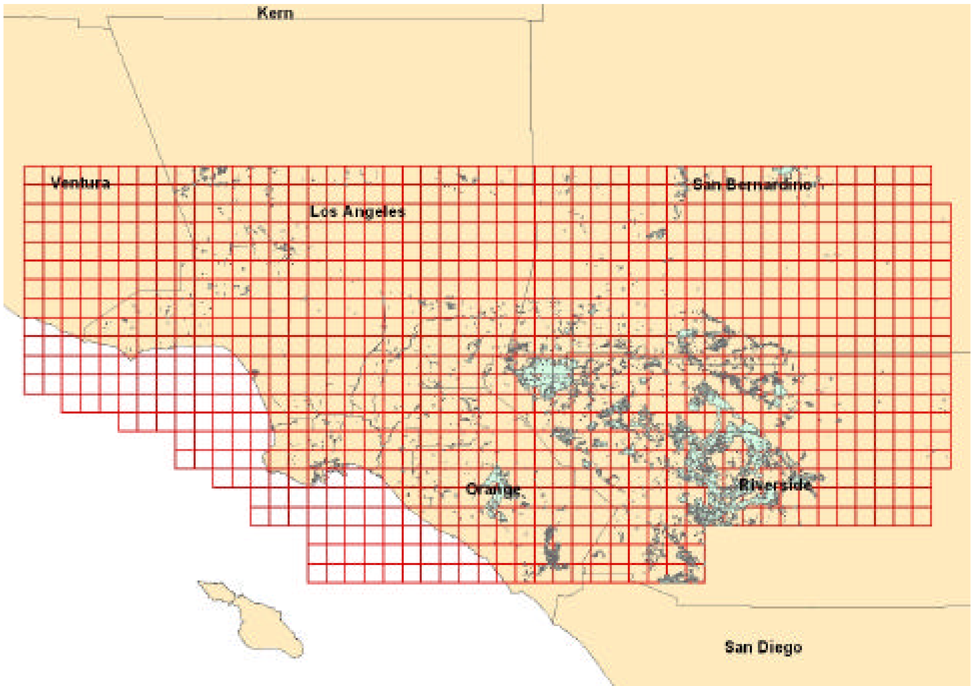


Figure 23: Location of land-use parcels pertaining to the Agriculture category

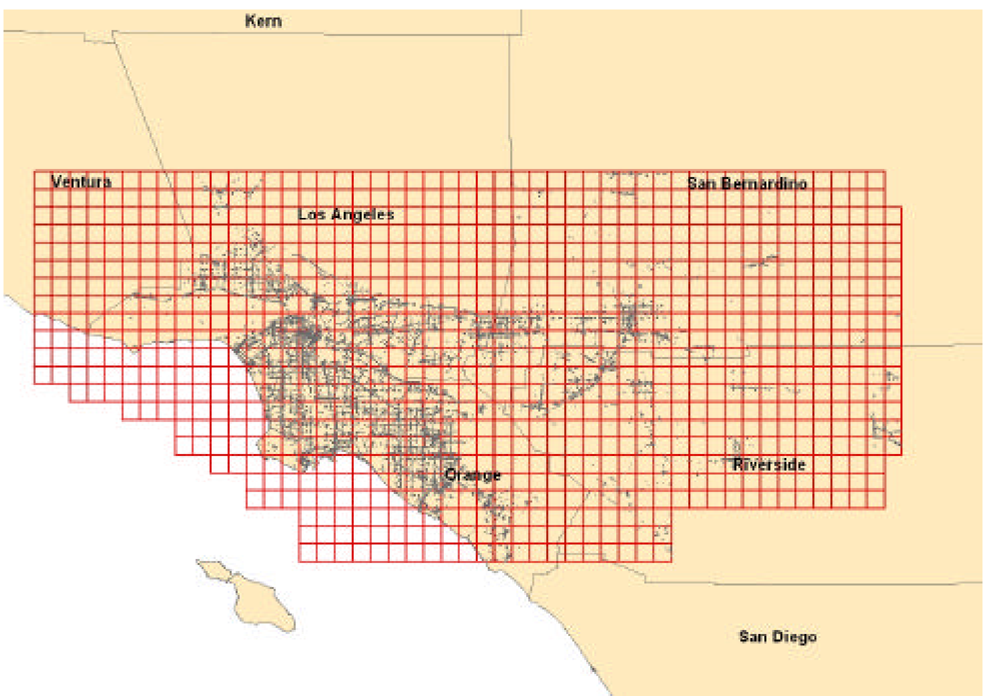


Figure 24: Location of land-use parcels pertaining to the Commercial category

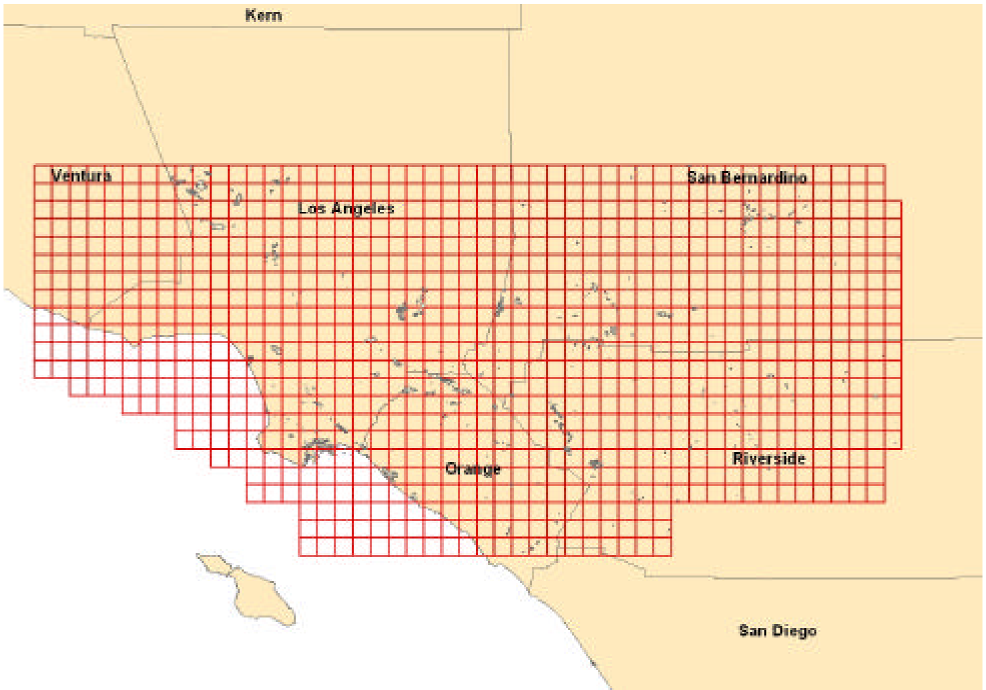


Figure 25: Location of land-use parcels pertaining to the Extraction category

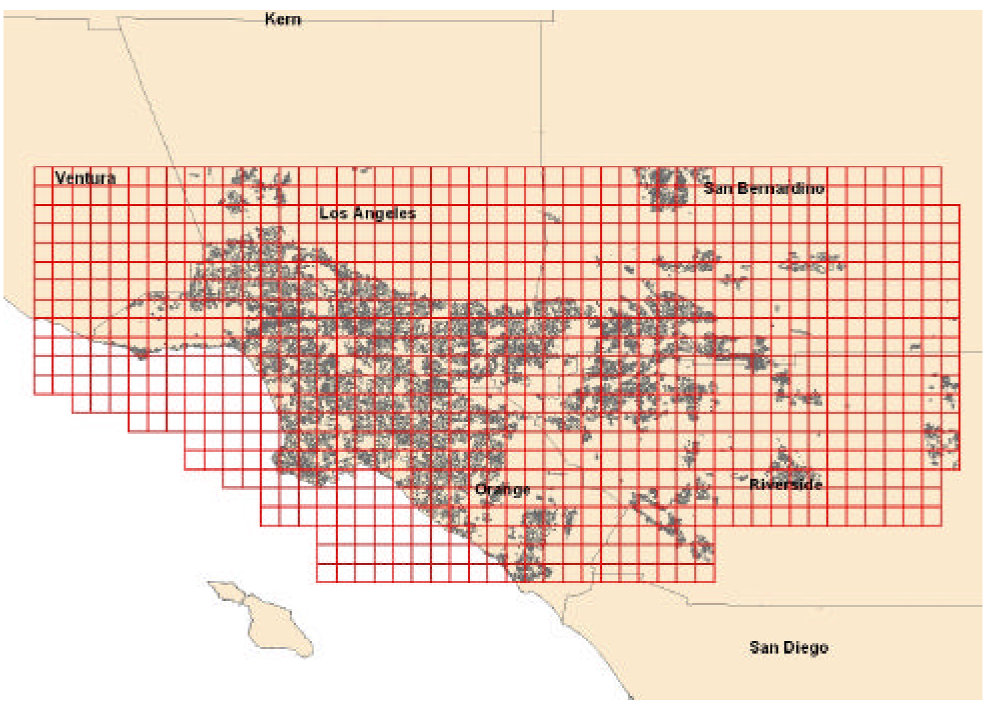


Figure 26: Location of land-use parcels pertaining to the Industrial category

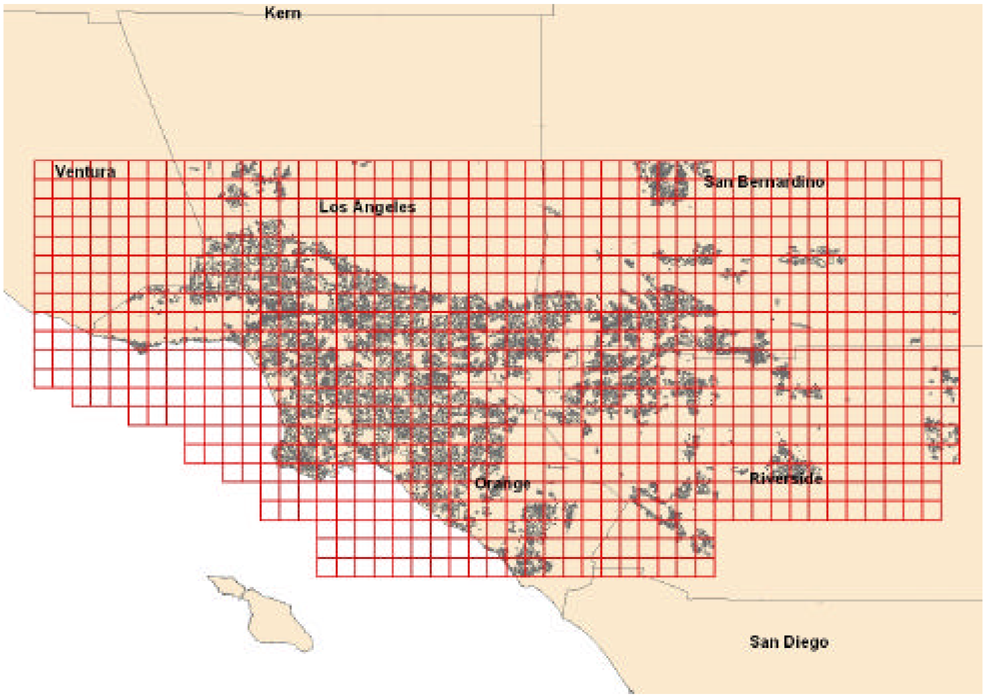


Figure 27: Location of land-use parcels pertaining to the Low Density Residential category

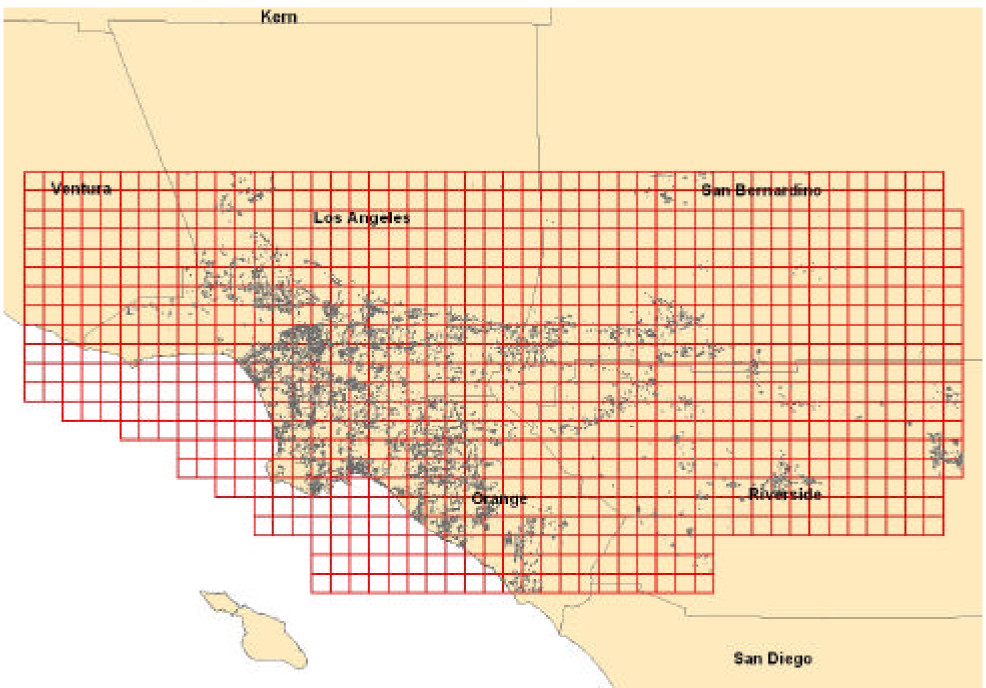


Figure 28: Location of land-use parcels pertaining to the Medium to High Density Residential category

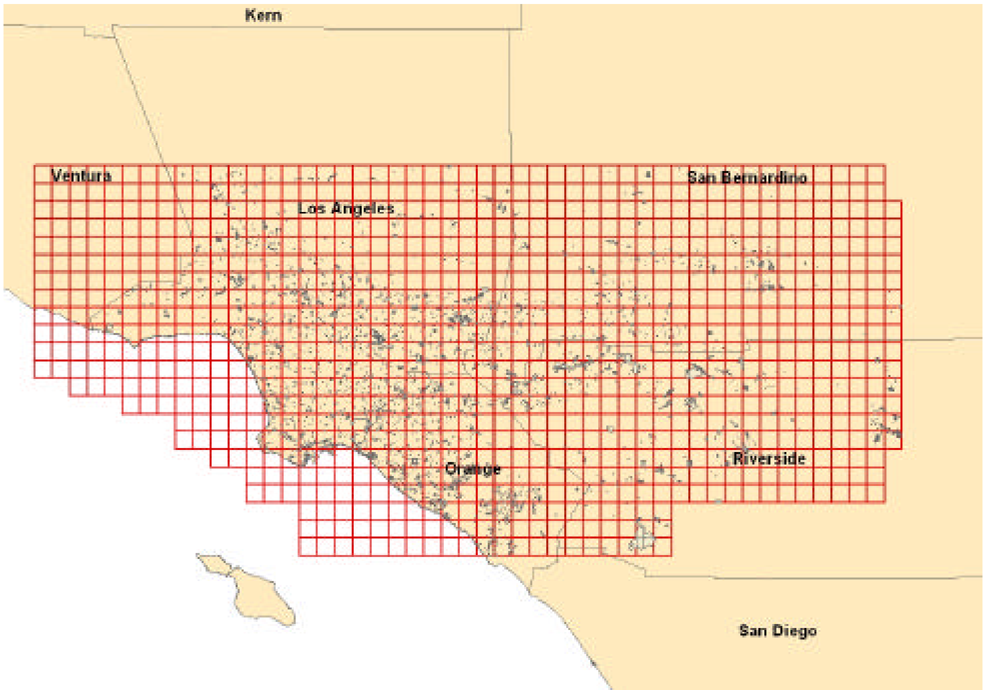


Figure 29: Location of land-use parcels pertaining to the Open Space and Recreation category

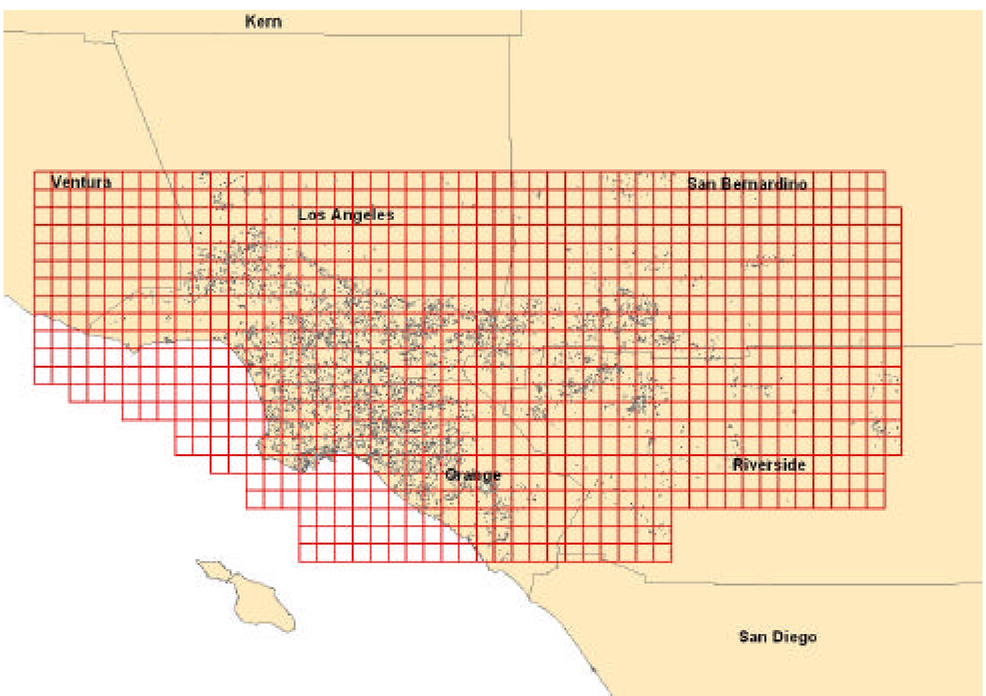


Figure 30: Location of land-use parcels pertaining to the Public Facilities and Institutions category

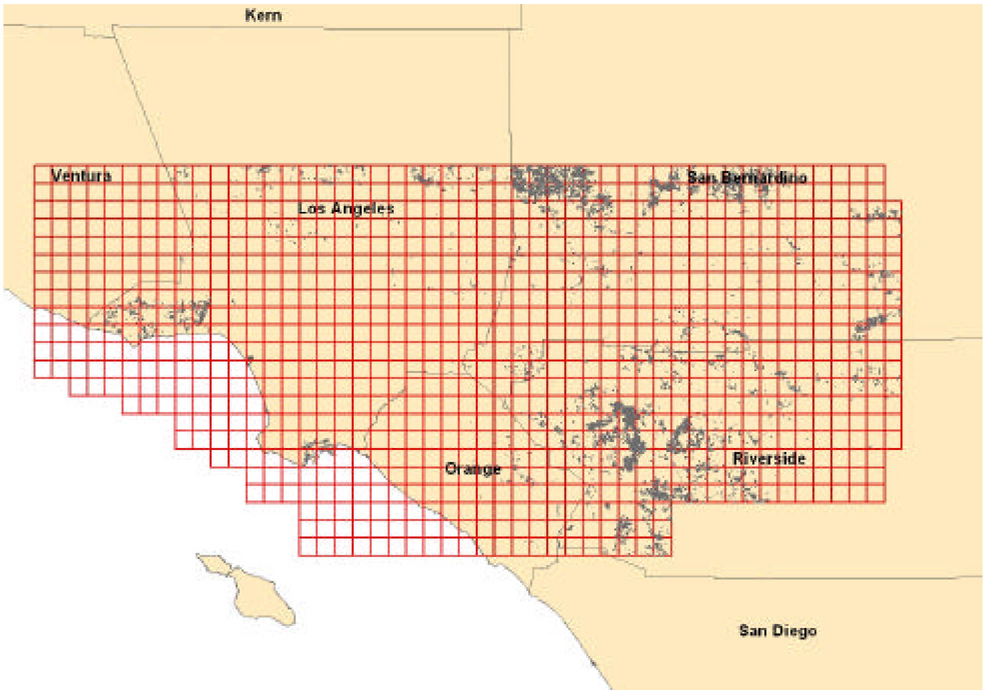


Figure 31: Location of land-use parcels pertaining to the Rural Density Residential category

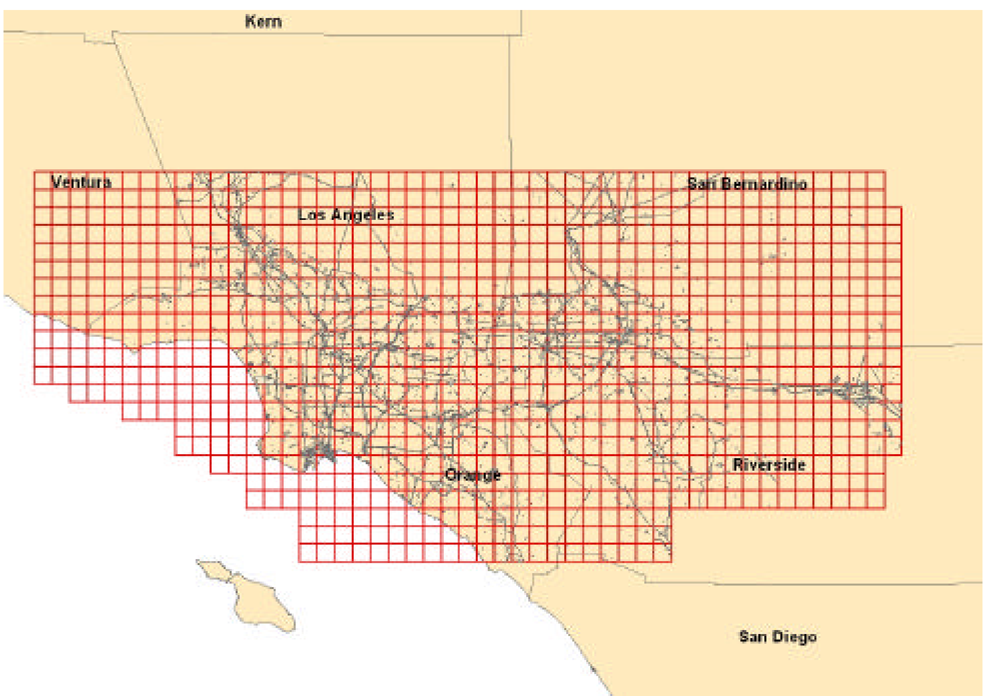


Figure 32: Location of land-use parcels pertaining to the Transportation and Utilities category

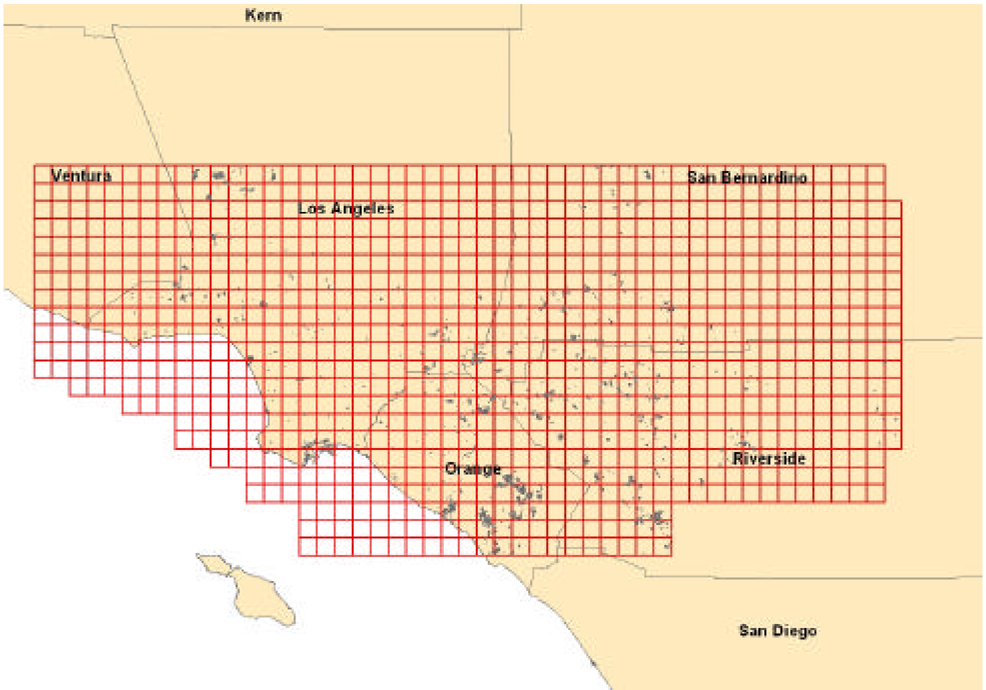


Figure 33: Location of land-use parcels pertaining to the Under Construction category

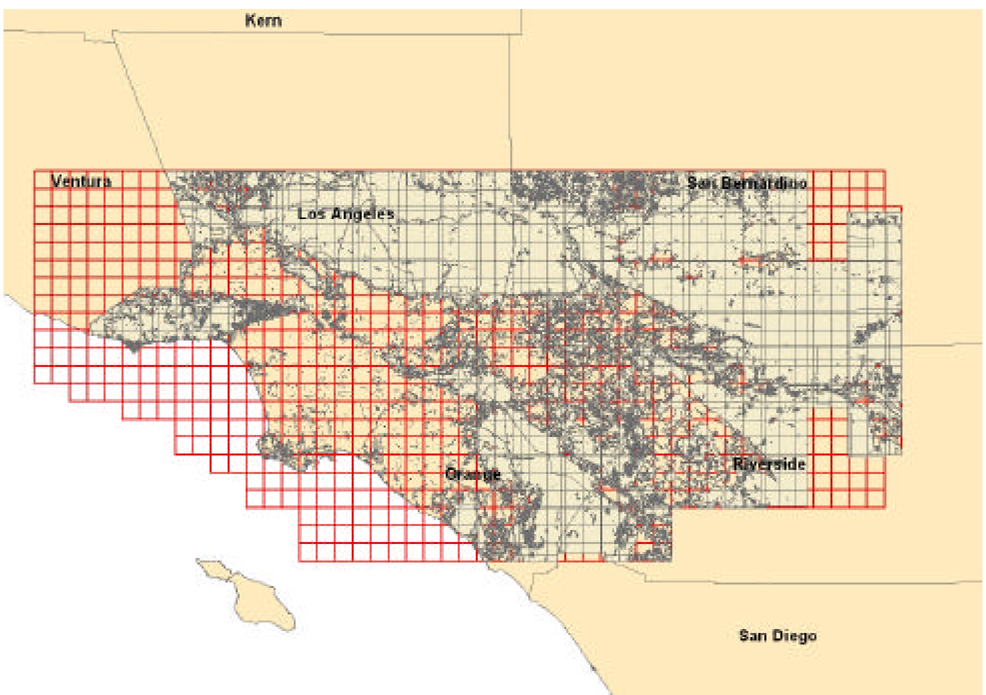


Figure 34: Location of land-use parcels pertaining to the Vacant category

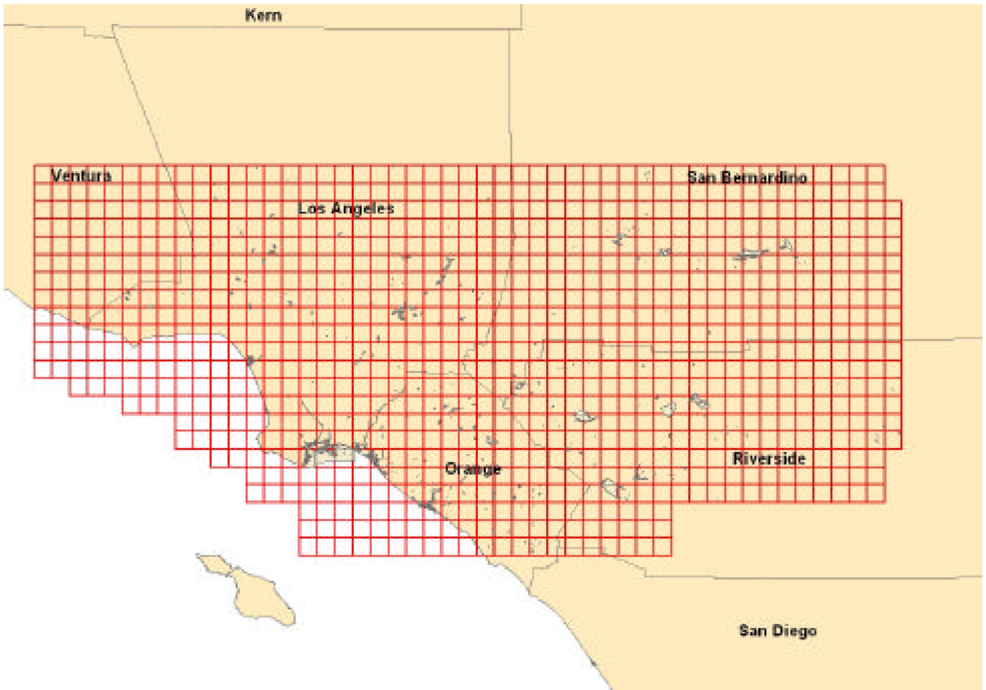


Figure 35: Location of land-use parcels pertaining to the Water and Floodways category

10 APPENDIX F: DUTY CYCLE APPROACH

Hourly electric load average profiles for the residential, commercial, agriculture and water pumping, and industrial sectors were downloaded from the Southern California Edison (SCE) web page. In the cases in which more than one load profile was available due to the different current rates, an aggregate load profile weighted by power demand was determined and applied in that sector. The "Other" sector category was assumed to have the same profile as the commercial aggregated electric load profile. Those profiles were normalized and applied in the systematic approach to develop realistic DG scenarios, as explained in the main text. Figure 36 through Figure 39 show the average profiles provided by SCE. The application of these profiles in the realistic DG scenarios will produce variable DG emission inventories for each hour of the day.

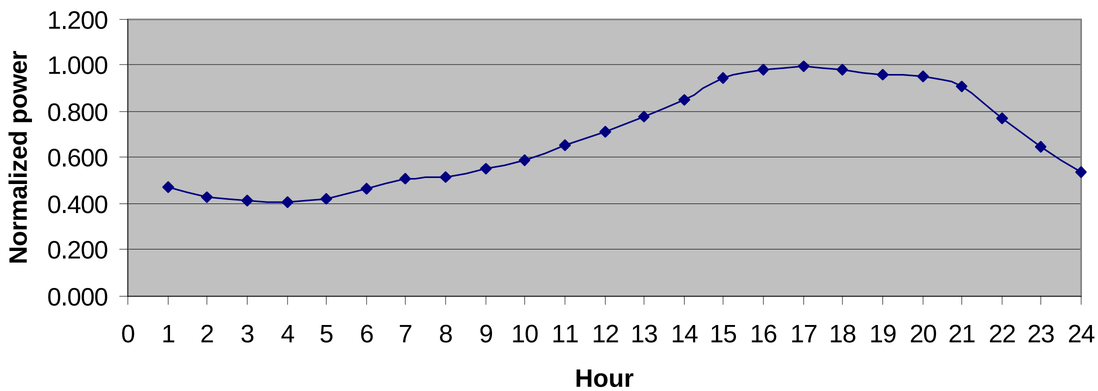


Figure 36: Normalized hourly electric profiles for SCE residential sector

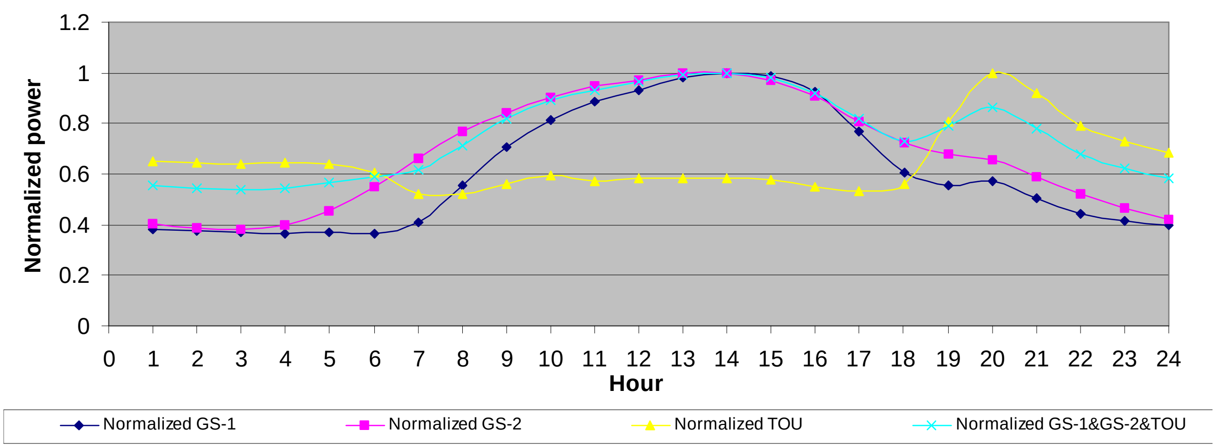


Figure 37: Normalized hourly electric profiles for SCE commercial sector

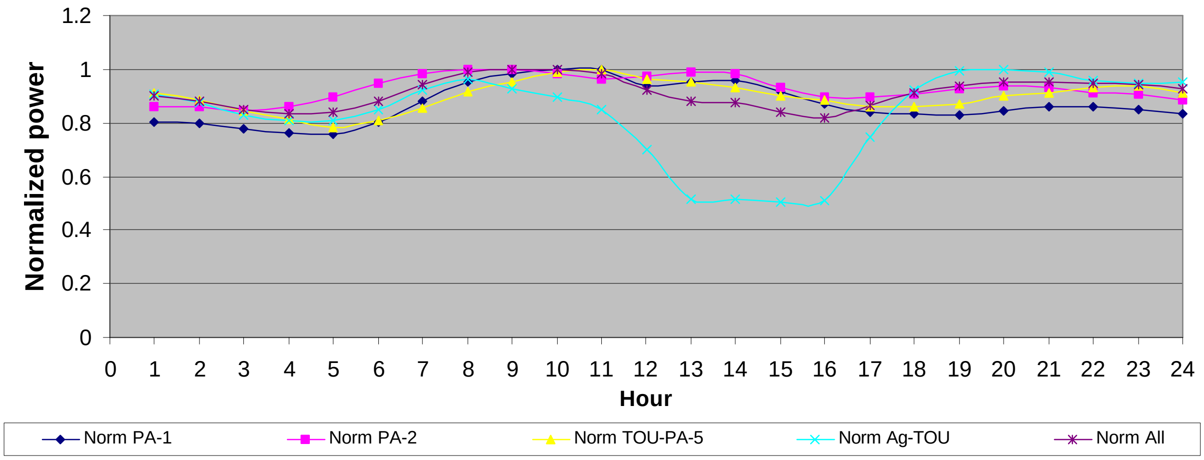


Figure 38: Normalized hourly electric profiles for SCE Agriculture and water pumping sector

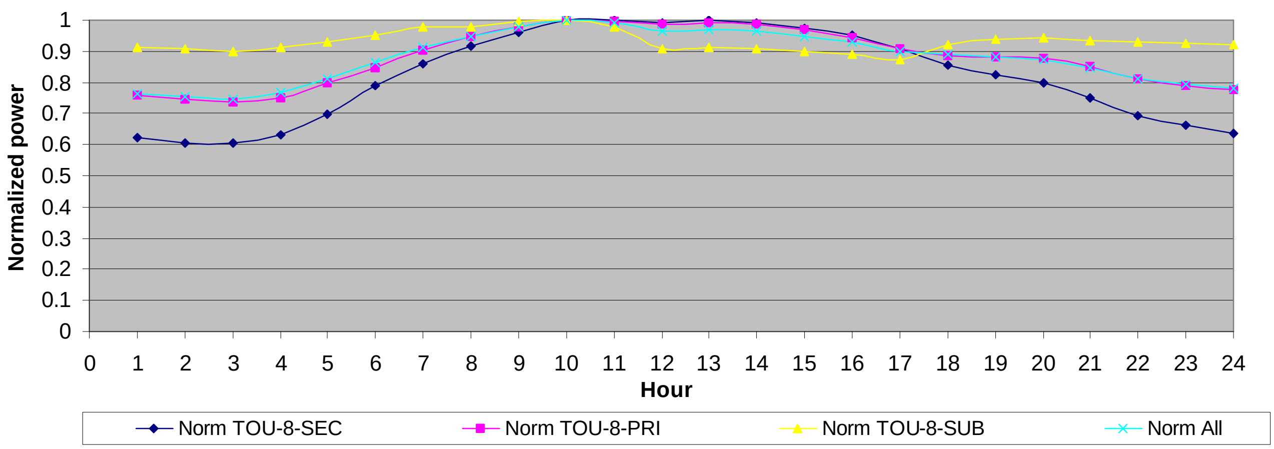


Figure 39: Normalized hourly electric profiles for SCE industrial sector